AEDC-TDR-63-67

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OPERATIONAL EVALUATION OF DRY-LUBRICANT COMPOSITES IN A HIGH VACUUM CHAMBER

By

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Aerospace Environmental Facility
ARO, Inc.

TECHNICAL DOCUMENTARY REPORT NO. AEDC-TDR-63-67

May 1963

AFSC Program Area 850E, Project 7778, Task 777801

(Prepared under Contract No. AF 40(600)-1000 by ARO, Inc., contract operator of AEDC, Arnold Air Force Station, Tenn.)

ARNOLD ENGINEERING DEVELOPMENT CENTER

AIR FORCE SYSTEMS COMMAND

UNITED STATES AIR FORCE

NOTICES

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a subsidiary of Sverdrup and Parcel, Inc.

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ARO Project No. SN2215

FOREWORD

Under research contract AF 40(600)-915 managed by USAF Space Systems Office, AEDC, Westinghouse Electric Corporation developed dry lubricants for use with moving mechanisms in large space simulation chambers. Mr. Paul Bowen, Westinghouse Project Engineer, contributed greatly to the planning and execution of tests described in this report.

ABSTRACT

This report contains the results of a test program to determine the operational characteristics of dry self-lubricating materials in the extremely low pressure environment of a space simulator. The test was designed to evaluate the lubrication of gears, pinions, and bearings.

Four selected self-lubricating composites fabricated as bearing retainers and idler gears were tested in the 7-Ft Aerospace Research Chamber at AEDC. Three of the composites consisted of a metal matrix, polytetrafluoroethylene (PTFE), and tungsten diselenide (WSe_2); the other consisted only of PTFE and WSe_2. The three composites with the metal matrix performed satisfactorily; the fourth material did not provide an adequate lubricating film on the gears which resulted in metal-to-metal contact and high wear.

PUBLICATION REVIEW

This report has been reviewed and publication is approved.

W. F. McRae
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Space Systems Office

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1.0 INTRODUCTION

It will be necessary to operate mechanical drive systems in space simulation chambers presently being constructed and contemplated at Arnold Engineering Development Center, (AEDC), Air Force Systems Command (AFSC). Handling provisions will be required to position and rotate test vehicles and other supporting test equipment. Conventional lubricants are not compatible with the extremely low pressures of space. They evaporate or sublimate at increasing rates as the chamber pressure decreases and as the temperature increases. Loss of the film which separates the metallic surfaces of the gears and bearings results in galling, seizure, and stalling of the rotating machinery.

A study to find possible solutions for this lubrication problem was sponsored by the Air Force under Contract No. AF 40(600)-915 with the Materials Laboratories, Westinghouse Electric Corporation, Pittsburgh, Pennsylvania. The object of the study was to adapt dry powders and/or dry self-lubricating materials for use in aerospace environmental chambers.

The Westinghouse study was organized into seven work phases. Phase I was concerned with screening dry self-lubricating materials. These materials were tested in an inert atmosphere using a Hohman type wear and friction tester. In Phase II selected materials from Phase I were heated over a range of temperatures and outgassing was measured. The most promising materials from Phase II were evaluated in functional tests in Phase III. These materials were fabricated into retainers for 20-mm ball bearings and were tested under a light radial load of 75 lb in a vacuum chamber. Test temperatures ranged from -60 to +450°F with limited operation at temperatures above 1000°F. Results obtained from Phases I, II, and III are reported in Ref. 1.

Improved self-lubricating materials suitable for use in heavily loaded bearings were developed and evaluated in Phase IV. The wear and friction characteristics of these materials were measured in air and a dry inert atmosphere. The most promising materials were used to fabricate retainers for ball bearings and idler gears. Outgassing rates for several of the materials developed in Phase IV were determined in Phase V. Results of the work done in Phase IV and V are reported in Ref. 2.

Manuscript received March 1963.

In Phase VI, new composite materials were developed, fabricated into usable forms, and evaluated for wear, friction, and outgassing characteristics. Under Phase VII, prototype models of bearings and gears using the most promising lubricants and application techniques were subjected to operational tests in the 7-Ft Aerospace Research Chamber at AEDC. The required operational conditions were 100 hr of operation at pressures below 1 x 10^{-6} torr and at temperatures between -60 and +300°F. This report describes the tests and the results obtained.

2.0 APPARATUS

2.1 FOUR-SQUARE GEAR TESTER

The equipment used to support and apply preset loads to the test gears is shown in Fig. 1. It consists of two parallel shafts, the drive shaft and the torsion shaft, rigidly supported on a stainless steel base plate. The diameter of the torsion shaft was 0.45 in., and the drive shaft had a diameter of 2.0 in. This design made it possible to measure the torque in the system from the torsion shaft by means of strain gages. The torsion shaft was provided with a torque coupler which was used to apply and lock any selected torque load into the system by twisting the shaft through loading screws.

Eight size 305 ball bearings supported the two shafts. Two were used at each end of each shaft. The parts of one bearing assembly are shown in Fig. 2. Each assembly consists of seven balls, an inner race, an outer race, and a retainer which supplied the lubricant. The retainer was fabricated by pressing the composite into the required form and strengthening it with an enclosing steel band.

The shafts were tied together through two sets of gears and pinions. The gears were installed on the drive shaft, and the pinions were installed on the torsion shaft. The gears had a pitch diameter of 6 in. and the pinions a 2-in. pitch diameter. The teeth on the gears and pinions had a diametrical pitch of 12, a pressure angle of 20 deg, and a face width of 3/4 in. Figure 3 shows the relative sizes of the gears, pinions, and idlers. The driving speed of the gears was approximately 34 rpm; therefore, the rotational rate of the torsion shaft was about 100 rpm. Materials used for the gears and pinions were representative of those used in drive mechanisms. Gear materials for each test are listed in Table 1. Lubrication of the gears and pinions was provided by use of idler gears which deposited the lubricant on the gears. Two test runs (nos. 5 and 6) were made with idlers on both the gears and pinions.

2.2 LUBRICANTS

The materials used for the bearing retainers and the idlers were of the same composition. The three ingredients were a powdered metal (copper, silver, or silver-bronze), a plastic, polytetrafluoroethylene (PTFE), and a metallic salt (WSe_2). The metal formed a matrix under moderate heat and high pressure which bound the mixture together. The plastic was the film-forming agent, and the metallic salt carried the normal loads. There were also overlapping functions between the components. The metal had a significant part in film formation, and it had a part in carrying the load. The plastic and the metallic salt were the lubricating agents. The ratio of metal, PTFE, and metallic salt was about 6:3:1 by weight; specific combinations for each test are listed in Table 1.

2.3 7-FT AEROSPACE RESEARCH CHAMBER

The 7-Ft Aerospace Research Chamber (Fig. 4) was used to provide the test environment. The inside dimension of the chamber is 7 ft diameter by 12 ft from door flange to door flange. Both ends are provided with doors which give a full 7-ft access to the chamber, as shown in Fig. 5. The pumping system for the chamber consisted of a 4 x 4-ft cryopanel cooled to temperatures below 20°K supported by two 32-in. and two 6-in. diffusion pumps in parallel backed by a single mechanical pump.

2.4 INSTRUMENTATION

Strain gages were used to measure the torque in the torsion and the drive shafts. Each set was made of four Microdot weldable sensors connected in a Wheatstone bridge configuration. A Twin-Viso Sanborn Instrument was used to record the signals.

Copper-constantan thermocouples were used as sensors for temperature measurements. The temperatures of rotating parts were measured at points shown in Fig. 6. The temperature of the supporting structure was measured at seventeen points. The average chamber temperature was recorded in the vicinity of the tester. A 24-point Brown recorder was used to record the temperatures.

Signals from the strain gages and the thermocouples on the rotating parts were transmitted to the recording equipment through slip-ring assemblies. These assemblies consisted of coin-silver rings, sintered silver alloy (silver, graphite, and molybdenum disulfide) brush contacts,

beryllium copper brush leaves, and polytetrafluoroethylene retainers. Figure 1 shows the sensor locations and slip-ring assemblies.

High brush wear and poor brush-ring contact were experienced in test 1 on the slip-ring assemblies. The brush wear problem was solved by installing solenoid actuators to lift the brushes when readings were not being made. The poor brush-ring contact was corrected by turning down the PTFE retainers and providing more clearance between the brush leaves and the retainers.

The chamber pressure was measured with two Bayard-Alpert-type ionization gages. One gage was located near the cryopanel, and the other was located to measure the chamber pressure near the four-square gear tester.

2.5 DRIVE AND ROTARY SEAL

The four-square tester was powered by a 1-hp Westinghouse motor through a belt-driven speed reducer, as shown in Fig. 4. The output speed was mechanically adjustable between 25 and 100 rpm.

In order that the drive mechanism could be located outside the chamber, a vacuum-tight rotary seal was developed. This seal used two guard vacuum cavities around the drive shaft, as shown in Fig. 7. The cavity nearest the drive motor was maintained at a reduced pressure between 1 and 10 microns by use of a mechanical pump. The cavity nearest the tester was maintained at pressures less than 1×10^{-5} torr by use of a 2-in. diffusion pump backed by a mechanical pump.

The performance of the rotary seal and drive assembly was excellent. The leak through the seal was negligible as compared to the remainder of the background gas load. Gaskets 1 and 2 (Fig. 7) were removed after tests 1 and 2 (200 hr) and examined. Gasket number 2 was worn slightly on the inside diameter because of a scratch on the shaft. New gaskets were installed, and the program was completed (350 hr) without the need for further adjustment or repair. At the end of the program, examination of the gasket revealed no sign of wear. The lowest sustained pressure (1×10^{-8} torr) was obtained after 250 hr operation on gaskets 1 and 2 and 450 hr on gasket 3 (representing nearly one million revolutions of the drive shaft).

2.6 HEATING AND COOLING PROVISION

Provisions were made to temperature cycle the Four-Square Gear Tester. The test hardware was cooled by use of liquid nitrogen cooling

coils. The cooling coils were located on the base plate, bearing supports, and on a hood positioned over the tester, as shown in Fig. 8. The tester components were heated by use of two 750-watt strip heaters on the base plate, two 2500-watt quartz lamps positioned inside the hood over the tester, and two 250-watt infrared lamps positioned to direct heat energy on the exposed ends of the tester.

3.0 PROCEDURE

3.1 CALIBRATION OF STRAIN GAGES

The strain gages were calibrated by applying known torque loads to the torsion and drive shafts and recording the needle deflection on the Sanborn Recorder. The procedure was to remove the drive shaft coupling shown in Fig. 5, remove the left pinion, and place a jamming bar between the base plate and the left gear teeth. Next, a lever arm was installed on the extended stub shaft on the left end of the torsion shaft, and the zero torque position was marked on the chart paper. Dead weights were hung on the lever arm at a distance of 10 in. from the centerline of the shaft. Thus by adding weights to the lever arm, the amount of torque was related to the needle deflection on the Sanborn Recorder. Typical calibration data are given in Fig. 9 for the torsion and the drive shafts.

3.2 ASSEMBLY AND PRE-TEST PROCEDURE

3.2.1 General

All test components (gears, pinions, idlers, and bearings) were marked for identification, cleaned, and weighed before assembly on the tester. The weighing was done on an analytical balance to an accuracy of ±0.01 g. Each item was photographed before it was tested

Spacers were used between bearing races and gear or pinion hubs to exactly align the matching gear and pinion teeth. After assembly was completed, the zero position of the strain-gage recorder was checked with no torque in the system. The gears were coated with a mixture of molybdenum disulfide and tungsten diselenide powder, a small torque load applied to the system, and then the system was run for approximately 30 min. After the run-in period, the gears were again coated with powder. Next, the test load was applied through the loading screws on the torque coupler. The unit was then run in air for 30 min. The test load and the recording instrument were again checked for proper operation by removing and reapplying the load.

After final checks were completed, the chamber was closed and pumped down. When the chamber pressure reached 1 x 10^{-6} torr, the tester was started.

3.2.2 Tests 1 through 5

The drive and torsion shafts available for test 1 were not structurally suitable for high loading conditions. Therefore, the test was run with a 150 in. -lb torque load applied to the gear teeth. Heat-treated shafts were available in test 2, which made it possible to apply more representative loads to the gear teeth. The left idler in test 3 had a gallium surface coat. For test 4 the unit was assembled without the no. 4 bearing, thus doubling the load on bearing no. 3, and the right pinion had a gallium-indium surface coat. Test 5 differed from previous tests in that an idler was mounted to ride on both the gears and pinions. The weights applied to the idlers for each test are given in Fig. 10.

3.2.3 Test 6

The assembly of test components for test 6 was the same as for test 5, except for the added provisions for cooling and heating. Before the test started, the chamber and test equipment were outgassed for ten hours at 300°F and then allowed to cool back to room temperature. Then the test hardware was cooled slowly by flashing liquid nitrogen through the cooling coils until all the test components reached an equilibrium temperature.

3.2.4 Test 7

To determine the effectiveness of lubrication, test 7 was conducted without gear lubricant. The test components were assembled as in previous tests with the exception that no idlers were mounted on the gears and pinions. In the pre-test procedure, the teeth of the gears and pinions were brushed and washed with alcohol to remove any grease or powdered lubricant that might be present. The drive shaft was equipped with a section designed to fail under a torque of 1000 in. -lb. Initially, a 500-in. -lb torque was applied, but the starting torque exceeded 1000 in. -lb. The load was then reduced to 350 in. -lb. This test was conducted last to preserve the structural integrity of the test hardware.

3.3 POST-TEST PROCEDURE

After each test period the chamber was pressurized with dry nitrogen gas and allowed to stand until the liquid nitrogen baffle surfaces warmed up to about 32°F. The dry nitrogen gas at room temperature causes faster warm-up of cold surfaces and prevents moisture condensation. Immediately

after the chamber was opened, the torque load remaining in the system and the zero position on the Sanborn recorder were checked. Then the test materials were removed, cleaned, weighed, and photographed. The bearings were shipped to Westinghouse for cleaning and weighing.

4.0 RESULTS

The changes in weight experienced by the gears, pinions, and idlers in the seven tests are tabulated in Table 2. The data for the bearings are tabulated in Table 3, and as no photographic distinction was apparent after the tests, pictures of the bearings are not shown. The chamber pressure for all the tests was maintained between 1×10^{-7} and 1×10^{-8} torr. Other results of the tests are presented in the following sections.

4.1 TEST 1

The torque in the torsion shaft apparently remained constant at 150 in.-lb throughout the test period. Continuous readings were not obtained because of the buildup of PTFE shavings between the rings and brushes on the slip-ring assemblies. No readings were made on the drive shaft for the same reason.

The temperature of the moving parts is given in Fig. 11. Figure 12 shows the test components after test. Wear on all gears and bearings was slight.

4.2 TEST 2

Torque data were not received through the slip-ring assemblies at the start of the test because of poor ring-brush contact. After 18 hr, the test was interrupted to clean and adjust the ring-brush assemblies. In order to reduce brush wear, solenoid actuators were installed to lift the brushes from contact with the rings when readings were not being made. When the test was resumed, torque data were obtained from the torsion shaft, but not from the drive shaft because of readout difficulties. Torque in the torsion shaft remained at 585 in.-lb during the rest of the test period.

The temperature of moving parts and the average temperature of the test chamber are given in Fig. 13. Figures 14 and 15 show the test components before and after test.

4.3 TEST 3

In test 3, the gear and pinion wear on the left gear assembly was greater than that on the right side. The left idler lost less weight than the right idler. A study of these conditions and the wear characteristics in test 2 point to a possible conclusion that heavier idler wear resulted in the disposition of a more continuous lubrication film on the gear and pinion teeth. The effect, if any, of the gallium surface coat is not apparent from available data.

The indicated torque in the torsion shaft (Fig. 16a) remained constant at 510 in.-lb throughout the test period. The driving torque increased slowly to 105 in.-lb and then remained constant. The temperatures of the chamber and the rotating parts are given in Fig. 16b. Figure 17 shows the test components after the test.

4.4 TEST 4

After 25 hr in test 4, the torque in the torsion shaft began to decrease, as shown in Fig. 18a. After 53 hr, the test was interrupted to check for the cause of the decreasing torque load. The gears and pinions were worn so badly that they jammed, and, as a result, the strain-gage section of the drive shaft failed during the checking operation.

Reference to Table 2 shows that the wear on the left gear was seven times greater than the wear on the right gear. The wear on the left pinion was 14 times greater than the wear on the right pinion. The wear on the left idler was 0.6 that of the wear on the right idler, even though the left idler was weighted twice as heavy as the right idler. These facts point to the possibility that the idler without the metal matrix was inefficient as a lubricant because a protective film was not deposited on the gear and pinion teeth. Figure 18b shows the temperature of the rotating parts and the average temperature of the chamber. Figures 19 and 20 show the condition of the gears, pinions, and idlers before and after test.

The bearing retainers were cracked in four out of seven locations, as noted in Table 3. It is believed that this damage occurred as a result of the gear seizure.

4.5 TEST 5

The torque values on the torsion and drive shafts are shown in Fig. 21a, and Fig. 21b gives the variation of temperature on the rotating parts and the chamber. During this test the gears were run for 87.5 hr, remained stationary for 48 hr, and then run for another 12.5 hr.

Figure 22 shows the condition of the gears and pinions after the test. From Table 2 and the photographs it is quite obvious that the wear on the gears and pinions was less than in previous tests. Wear on some of the idler teeth was also less than in previous tests.

4.6 TEST 6

The torque and temperature readings for test 6 are given in Fig. 23. The equipment was operated at temperatures below -90°F for 40 hr and at temperatures above 280°F for 40 hr.

The condition of the gears and pinions after test is shown in Fig. 24. As in test 5, the loss of material from the gears and pinions was slight (Table 2), indicating staisfactory operation at the different temperatures.

4.7 TEST 7

Test 7 was conducted to establish a base from which to evaluate the effectiveness of the lubricating materials tested in this program. Rotation of the gear assembly became jerky shortly after the drive motor was started. This jerky motion was probably caused by momentary seizure between the teeth of the gears and pinions. When the torque required to overcome this seizure exceeded 1000 in.-lb, the drive shaft twisted and failed. The run time was 1 hr and 43 min. Although not much material was lost from the gears in this test (Table 4), it is apparent from Fig. 25 that the gear surfaces sustained considerable damage.

5.0 DISCUSSION OF RESULTS

All the materials tested in this program performed satisfactorily with the exception of one idler material. The PTFE-WSe_2 material used to lubricate the left gear assembly in test 4 failed to provide a protective film. The result was excessive tooth wear and consequent jamming of the gear-pinion assembly after 53 hr of operation. In all other tests where self-lubricating materials were used, the components were suitable for operation beyond the 100-hr period. This lack of effective lubrication for the PTFE-WSe_2 material is believed to be related to the absence of the metal bonding agent. When compared to the results obtained from test 7 with no lubricant, it is apparent that the PTFE-WSe_2 did reduce the friction between the teeth even though the wear rate was higher than in other tests with lubricants. The combined effect of low temperature and low

pressure or the combined effect of high temperature and low pressure (test 6) did not significantly change the lubricating properties of the test materials.

The load applied to the gears in this program represents the maximum safe tangential load at the pitch diameter for plain cast-iron gears. The load was approximately 25 percent of the maximum safe tangential load for S. A. E. 1045 carbon steel and nodular iron as calculated by the Lewis Gear Formula. The pinions were loaded to 50 percent of the safe load for cast iron and approximately 10 percent of the safe load for the steels.

Wear on the bearings was slight in all cases. The appearance of the bearing component surfaces and a small increase in the diameter of the balls indicated the presence of a protective film from both the copper and silver composites. In two cases, the same bearings were used in two test runs. This means that they were performing well after 200 hr of operation under a load equal to approximately 10 percent of the rated capacity with normal lubrication.

6.0 CONCLUDING REMARKS

The gears tested in this program performed well when lubricated with the three component composites under the applied test conditions. These results point to a possible solution for the lubrication of certain types of rotating equipment, such as speed reducers in a space simulator. However, further investigations are necessary to apply this lubricating technique to other design requirements which currently exist in space environmental chambers.

REFERENCES

1. Bowen, P. H. "Analytical and Experimental Study of Adapting Bearings for Use in an Ultra-High Vacuum Environment, Phase I, II and III." AEDC-TDR-62-51, February 1962.

2. Bowen, P. H. "Analytical and Experimental Study of Adapting Bearings for Use in an Ulta-High Vacuum Environment, Phase IV and V." AEDC-TDR-62-163, August 1962.

TABLE 1

TEST MATERIALS LISTED BY TEST AND POSITION

Test #	Left Gear Assembly			Right Gear Assembly			52100 Steel Bearings		Applied Load on Teeth	Test Duration and Drive Shaft Speed
	Gear	Pinion	Idler	Gear	Pinion	Idler	Retainer	Load		
1	1045 Steel	1045 Steel	Copper PTFE Tungsten-Diselenide	1045 Steel	1045 Steel	Copper PTFE WSe_2	Copper PTFE WSe_2	75	150	100 hr 47. 4 rpm
2	Cast Iron Tensile 35, 000	Cast Iron	Silver PTFE WSe_2	Cast Iron	Cast Iron	Silver PTFE WSe_2	Silver PTFE WSe_2	293	585 Hertz Stress 110, 000 psi	100 hr 33. 1 rpm
3	Cast Iron	Cast Iron	Silver PTFE WSe_2 (*)	Cast Iron	1045 Steel	Silver-Bronze PTFE WSe_2	Copper PTFE WSe_2 (**)	255	510	92 hr 34. 7 rpm (Test Terminated at End of Work Week)
4	Cast Iron	Cast Iron	PTFE WSe_2	Cast Iron	1045 Steel (***)	Silver-Bronze PTFE WSe_2	Silver PTFE WSe_2	285 on One Side and 500 on Other	570	53 hr 34. 5 rpm (Gears Seized)
5	Nodular Iron	1045 Steel	Silver PTFE WSe_2 on Gear Silver-Bronze Teflon WSe_2 on Pinion	Nodular Iron	1045 Hardened Steel	Silver-Bronze PTFE WSe_2 on Both Gear and Pinion	Copper PTFE WSe_2	250	500	100 hr 34. 5 rpm
6	Nodular Iron	Nodular Iron (*)	Silver PTFE WSe_2 on Both Gear and Pinion	Nodular Iron	Hardened Steel	Silver PTFE WSe_2 on Both Gear and Pinion	Silver PTFE WSe_2 (****)	250	500	100. 5 hr 34. 6 rpm
7	1045 Steel (*)	1045 Steel	None	1045 Steel	1045 Steel	None	Copper PTFE WSe_2 (**)	175	350 (Would Not Turn with 500)	1 hr 43 min 35. 2 rpm (Gears Seized)

(*) With gallium surface coat.
(**) The same bearings were used in test no. 1.
PTFE Polytetrafluoroethylene
(***) With gallium-indium surface coat.
(****) The same bearings were used in test 2.

TABLE 2

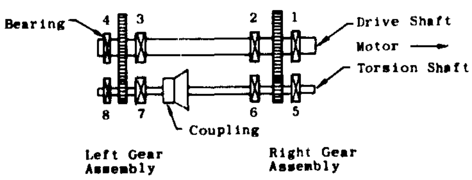
INITIAL WEIGHT AND CHANGE IN WEIGHT OF GEARS, PINIONS, AND IDLERS

Test	Left Gear Assembly			Right Gear Assembly		
	Gear	Pinion	Idler	Gear	Pinion	Idler
1	#G2 3,320.97 g -0.05 g	#P2 218.47 g -0.19 g	#I13 295.47 g -1.6 g	#G1 3,314.72 g -0.05 g	#P1 218.35 g -0.15 g	#I12 274.47 g -0.68 g
2	#G102 1,357.45 g -3.65 g	#P109 203.61 g -0.71 g	#I2 280.93 g -0.83 g	#G108 1,380.48 g -3.13 g	#P108 202.63 g -0.57 g	#I1 279.76 g -0.66 g
3	#G104 1,381.15 g -1.78 g	#P104 203.21 g -0.28 g	#I8 306.16 g -1.01 g	#G103 1,356.32 g -1.00 g	#P6 218.25 g -0.19 g	#I9 314.53 g -1.18 g
4	#G105 1,377.13 g -16.70 g	#P105 203.21 g -3.81 g	#I26 197.39 g -0.75 g	#G109 1,377.37 g -2.41 g	#P10 218.30 g -0.27 g	#I25 271.01 g -1.27 g
5	#G111 2,407.51 g +0.04 g	#P1 218.19 g -0.06 g	#I3 267.62 g -0.82 g #I24 274.33 g -0.80 g	#G110 2,407.45 g -0.03 g	#P2 218.27 g -0.03 g	#I10 311.09 g -0.22 g #I11 308.88 g -0.33 g
6	#G110 2,407.45 g -0.08 g	#P110 202.60 g 0.0 g	#I33 308.61 g -0.37 g #I35 300.73 g -0.09	#G111 2,407.51 g +0.07 g	#P11 218.10 g -0.15 g	#I31 309.05 g -0.80 g #I32 311.01 g -0.81 g
7	#G10 3,318.89 g -0.42 g	#P7 295.20 g +0.10 g	None ---- ----	#G5 3,324.30 g -0.08 g	#P8 295.20 g +0.02 g	None ---- ----

TABLE 3
TABULATED BEARING DATA

Test Number	Bearing Number	Location (See Sketch)	Outer Race	Inner Race	Ball	Retainer	Retainer Material
1	B103	1	Weight Change was insignificant in all cases.				Cu-PTFE-WSe_2
	B104	2					"
	B105	3					"
	B107	4					"
	B501-51	5					"
	B502-52	6					"
	B503-53	7					"
	B504-54	8					"
2	B301	1	-0.0021	-0.0020	+0.0027	-0.0360	Ag-PTFE-WSe_2
	B302	2	-0.0013	-0.0028	+0.0003	-0.0292	"
	B303	3	-0.0011	-0.0018	+0.0006	-0.0107	"
	B304	4	-0.0012	-0.0021	+0.0004	-0.0082	"
	B305	5	-0.0014	-0.0039	+0.0032	-0.0494	"
	B306	6	-0.0021	-0.0028	-0.0003	-0.0260	"
	B307	7	-0.0033	-0.0030	+0.0010	-0.0090	"
	B308	8	-0.0028	-0.0056	-0.0013	-0.0052	"
3	B103	1	-0.0054	-0.0025	+0.0006	-0.0074	Cu-PTFE-WSe_2
	B104	2	-0.0034	-0.0019	+0.0006	-0.0087	"
	B105	3	-0.0057	-0.0039	+0.0002	-0.0162	"
	B107	4	-0.0045	+0.0043	+0.0021	-0.0130	"
	B501-51	5	-0.0017	-0.0005	+0.0017	-0.0155	"
	B502-52	6	-0.0020	-0.0012	+0.0010	-0.0159	"
	B503-53	7	-0.0016	-0.0002	+0.0022	-0.0190	"
	B504-54	8	-0.0014	-0.0019	-0.0001	-0.0103	"
4	B505	1	-0.0038	-0.0042	-0.0005	-0.0124	Ag-PTFE-WSe_2
	B509	2	-0.0032	-0.0021	+0.0014	-0.0074	"
	B510	3	-0.0029	-0.0017	-0.0001	-0.0131	"
	None	4	-	-	-	-	"
	B314	5	-0.0014	-0.0012	+0.0017	-0.2460*	"
	B315	6	-0.0037	-0.0030	+0.0018	-0.0209	"
	B316	7	-0.0039	-0.0018	+0.0016	-0.0478	"
	B318	8	-0.0036	-0.0035	+0.0026	-0.0397	"
5	B106	1	-0.0070	-0.0029	+0.0011	-0.0197	Cu-PTFE-WSe_2
	B110	2	-0.0059	-0.0039	+0.0003	-0.0133	"
	B309	3	-0.0079	-0.0059	+0.0005	-0.0074	"
	B312	4	-0.0071	-0.0032	+0.0008	-0.0189	"
	B317	5	-0.0043	-0.0033	-0.0001	-0.0162	"
	B506	6	-0.0032	-0.0018	+0.0025	-0.0306	"
	B507	7	-0.0052	-0.0032	+0.0093	-0.0299	"
	B508	8	-0.0046	-0.0035	-0.0005	-0.0291	"
6	B301	1	-0.0026	+0.0005	-0.0027	-0.0180	Ag-PTFE-WSe_2
	B302	2	-0.0024	-0.0048	+0.0001	-0.0210	"
	B303	3	-0.0026	-0.0044	-0.0001	-0.0225	"
	B304	4	-0.0041	-0.0046	-0.0001	-0.0237	"
	B305	5	-0.0023	-0.0040	-0.0036	-0.0163	"
	B306	6	-0.0033	-0.0042	-0.0002	-0.0097	"
	B307	7	-0.0008	-0.0044	-0.0007	-0.0208	"
	B308	8	-0.0048	-0.0043	-0.0006	-0.0114	"
7**	B103	1	Wear was insignificant.				Cu-PTFE-WSe_2
	B104	2					"
	B105	3					"
	B107	4					"
	B501-51	5					"
	B502-52	6					"
	B503-53	7					"
	B504-54	8					"

* Chipped
** Retainers in bearing positions 1, 3, 5, and 8 cracked



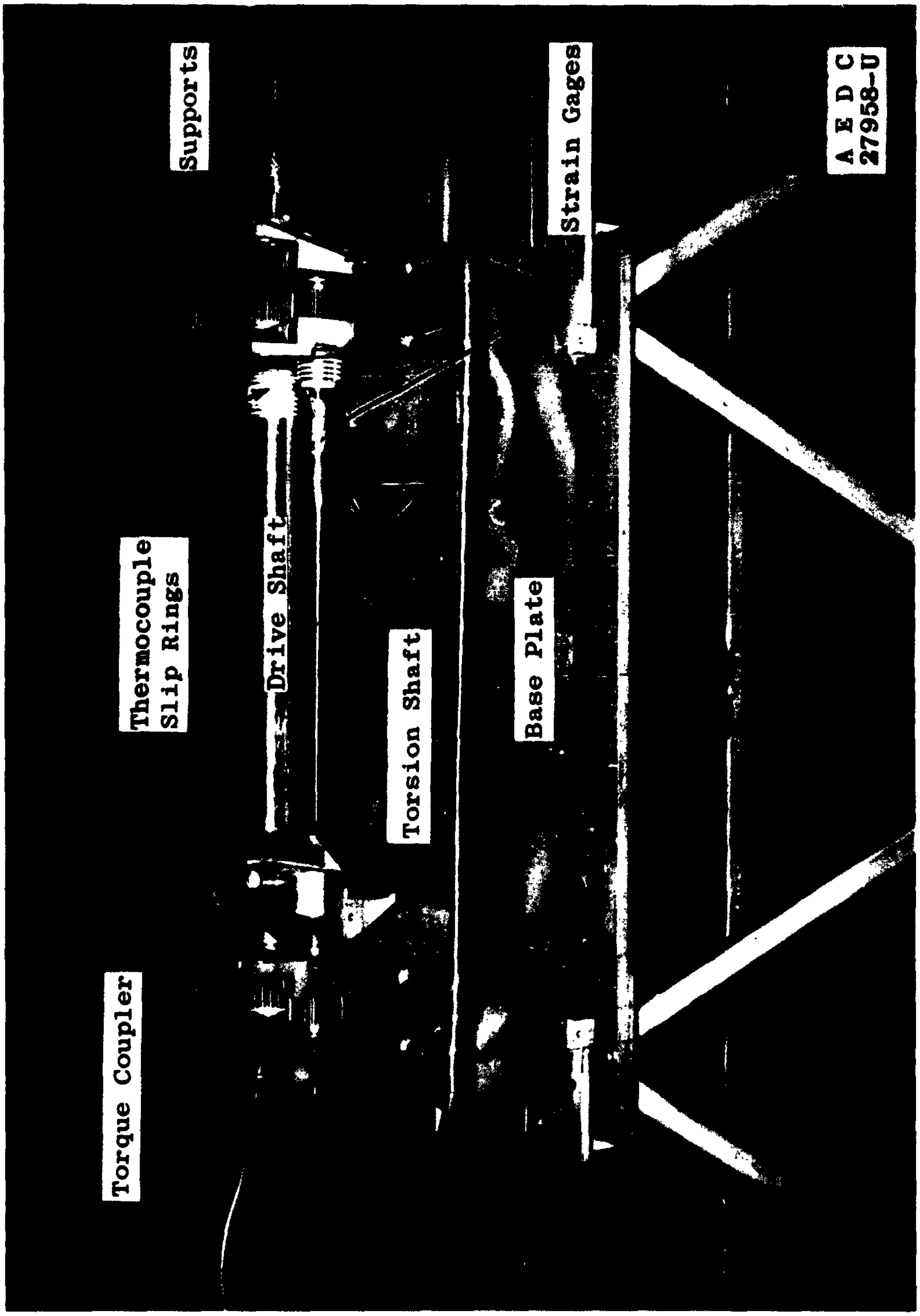


Fig. 1 Four-Square Gear Tester

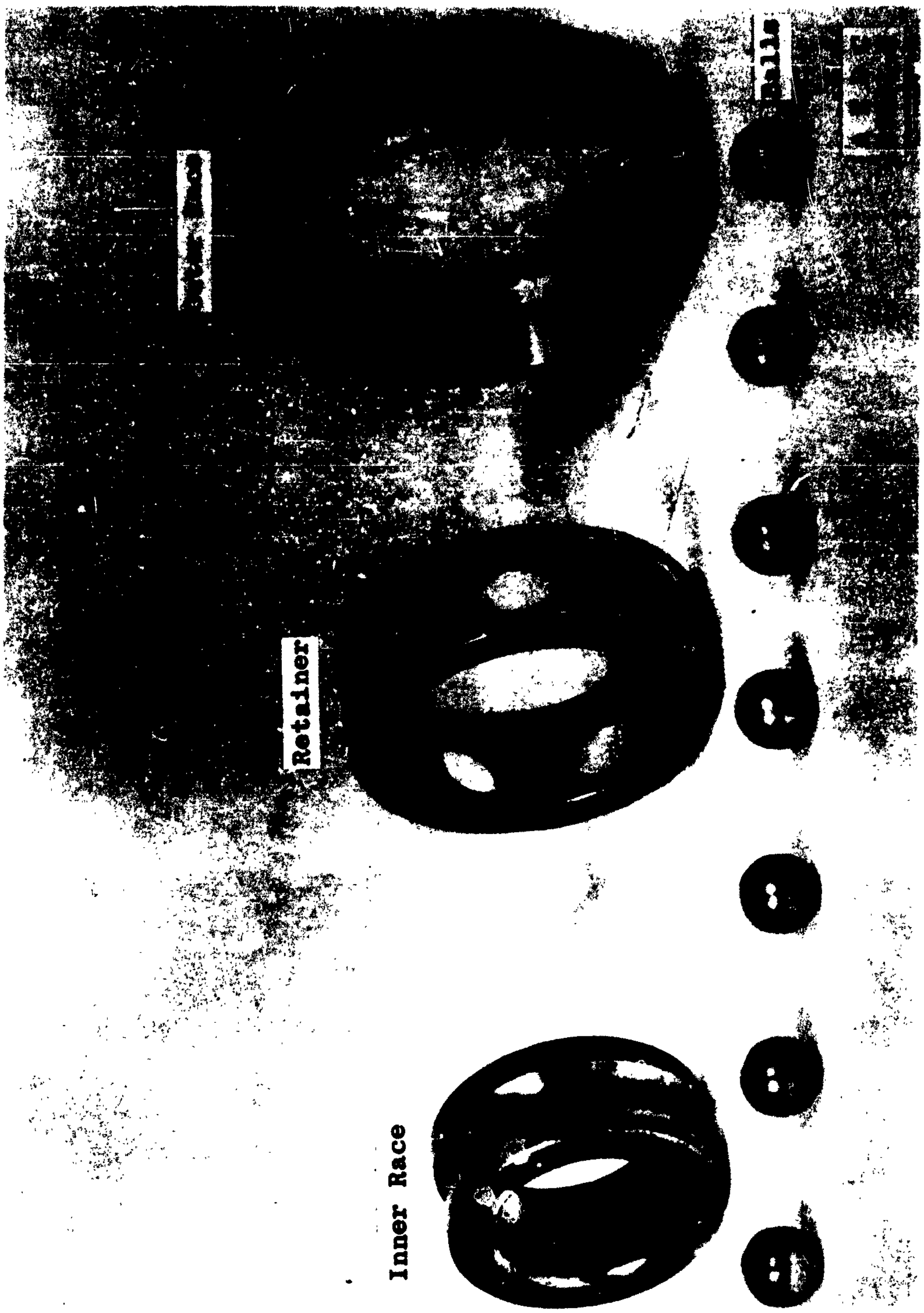


Fig. 2 Bearing

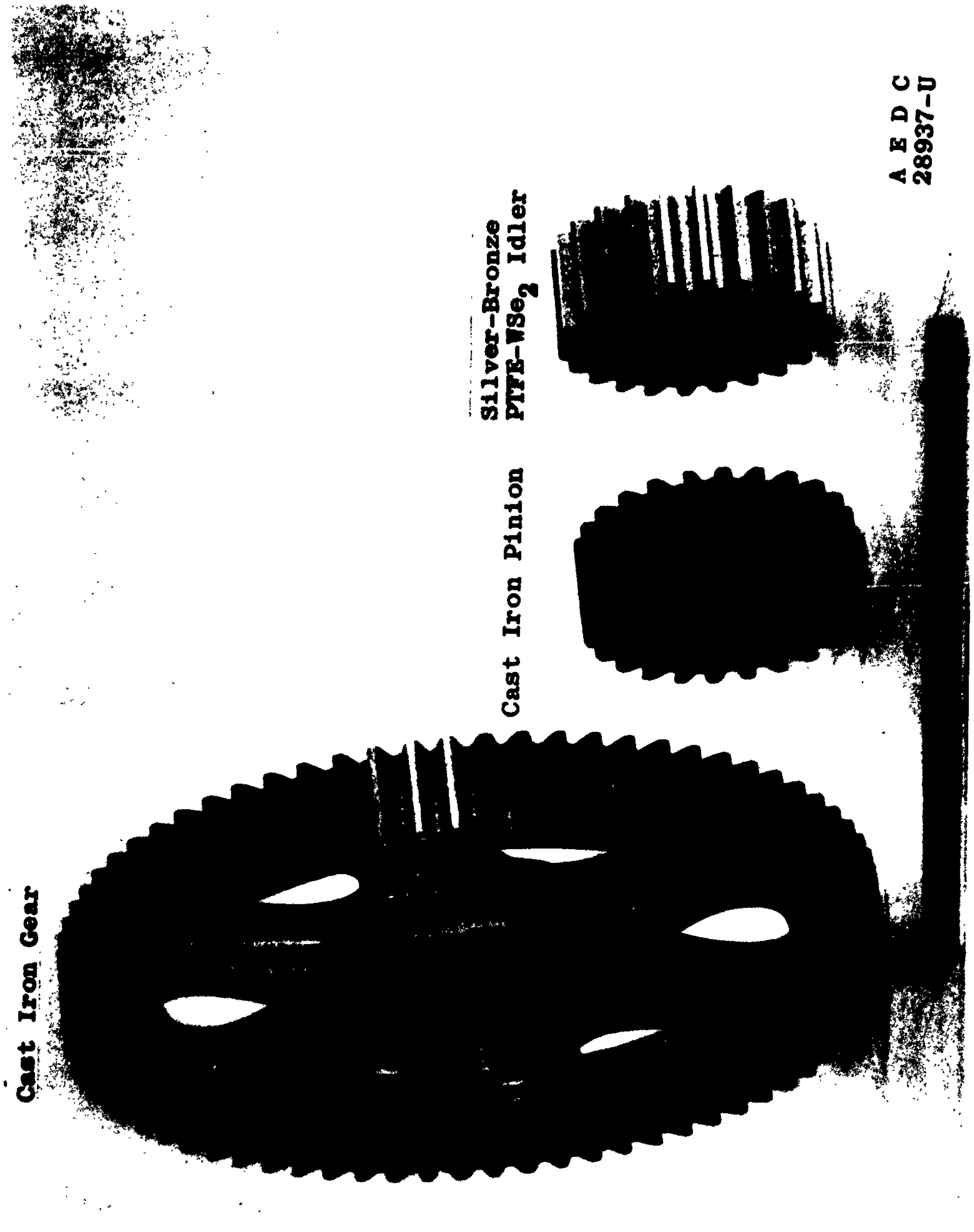


Fig. 3 Gear, Pinion, and Idler

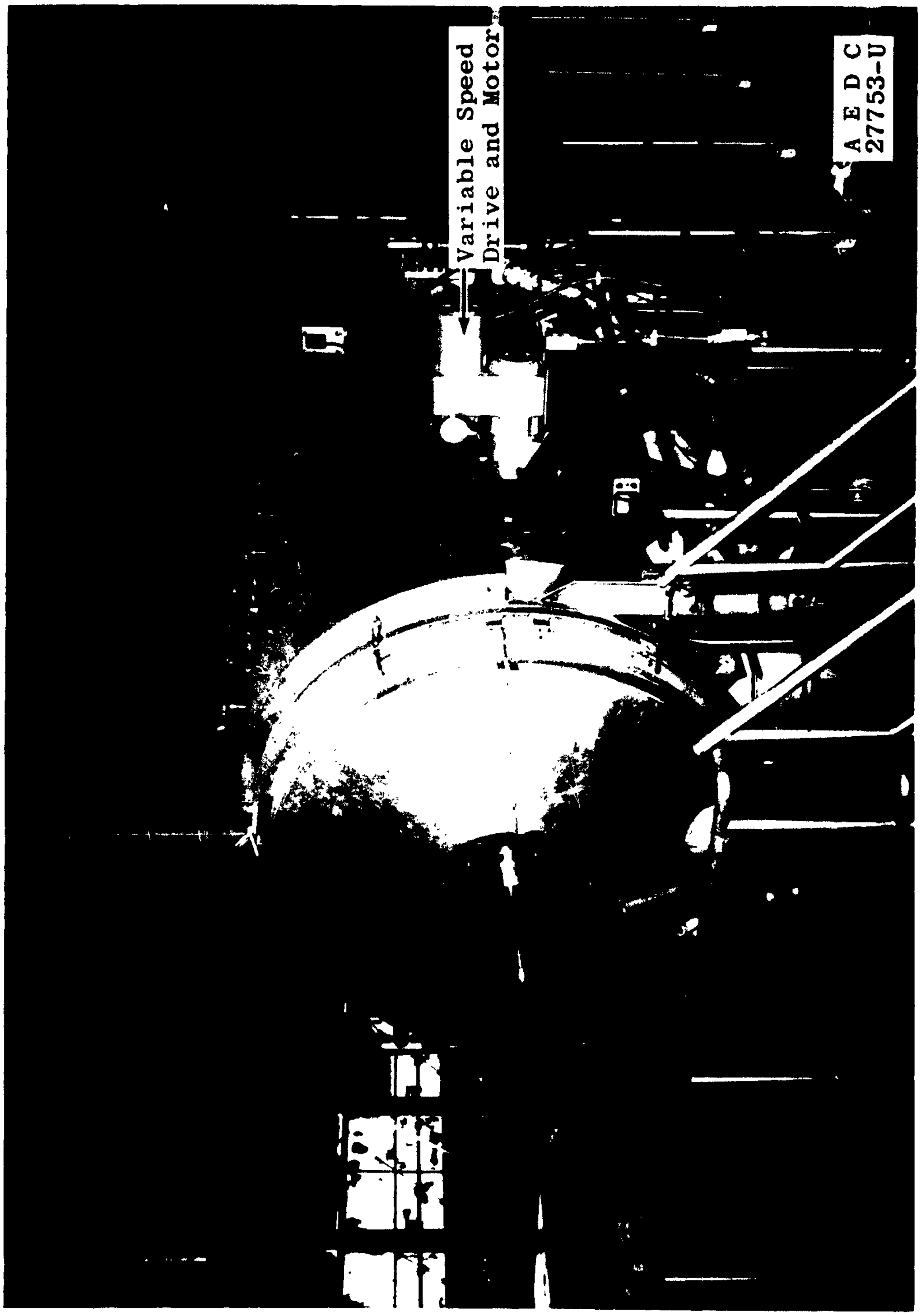


Fig. 4 7-Ft Aerospace Research Chamber

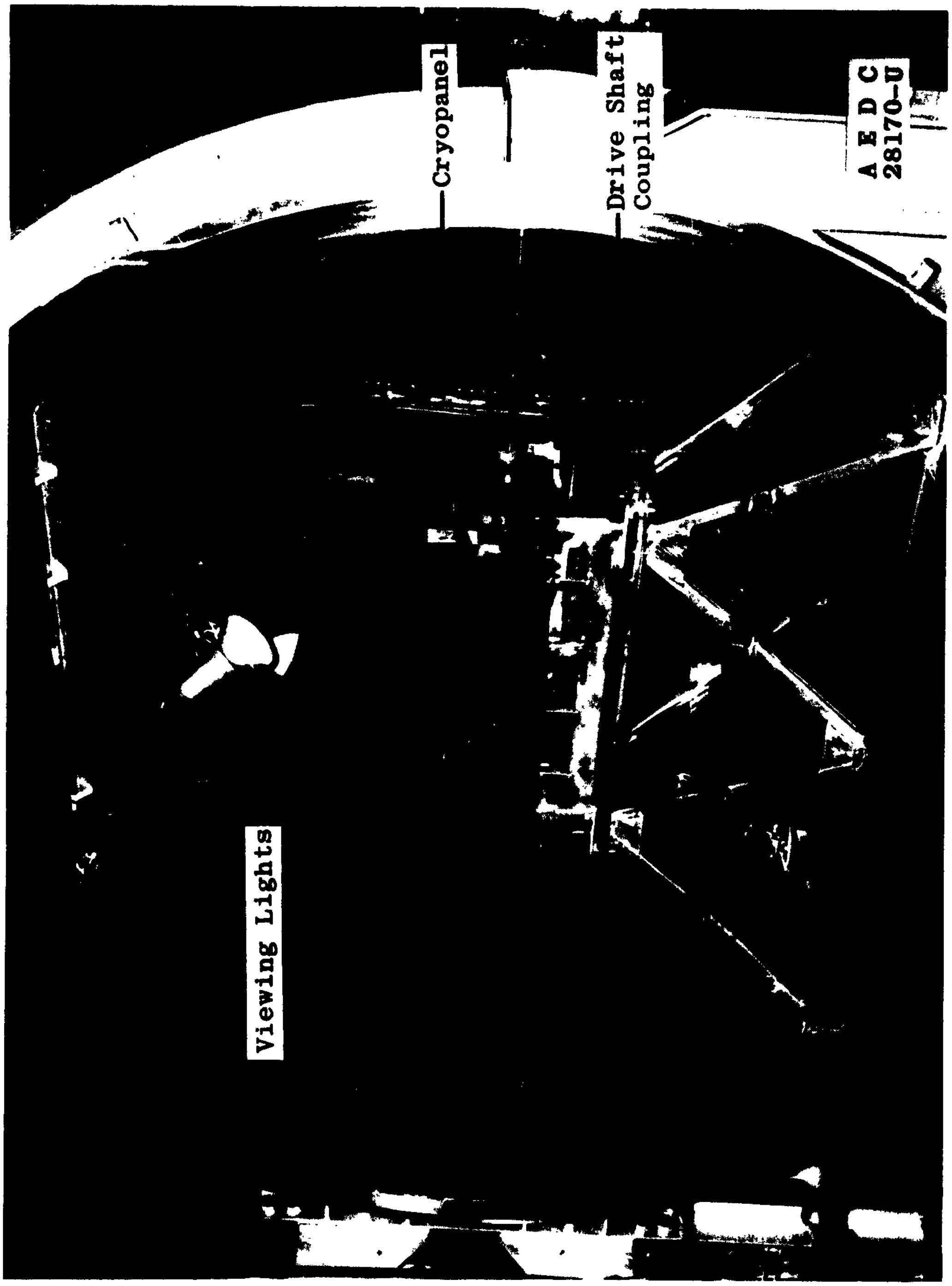


Fig. 5 Test Hardware in the 7-Ft Aerospace Research Chamber

Thermocouple No.	Position
1	Bearing No. 2, Inner Race
2	Gear, Inner Bore
3	Gear, Outer Tooth
4	Bearing No. 1, Inner Race

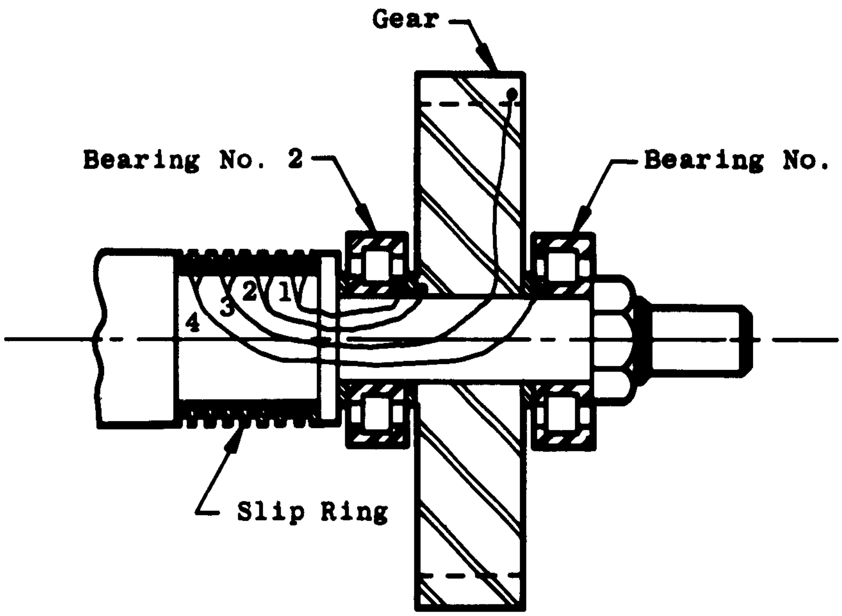


Fig. 6 Thermocouple Location on Rotating Parts

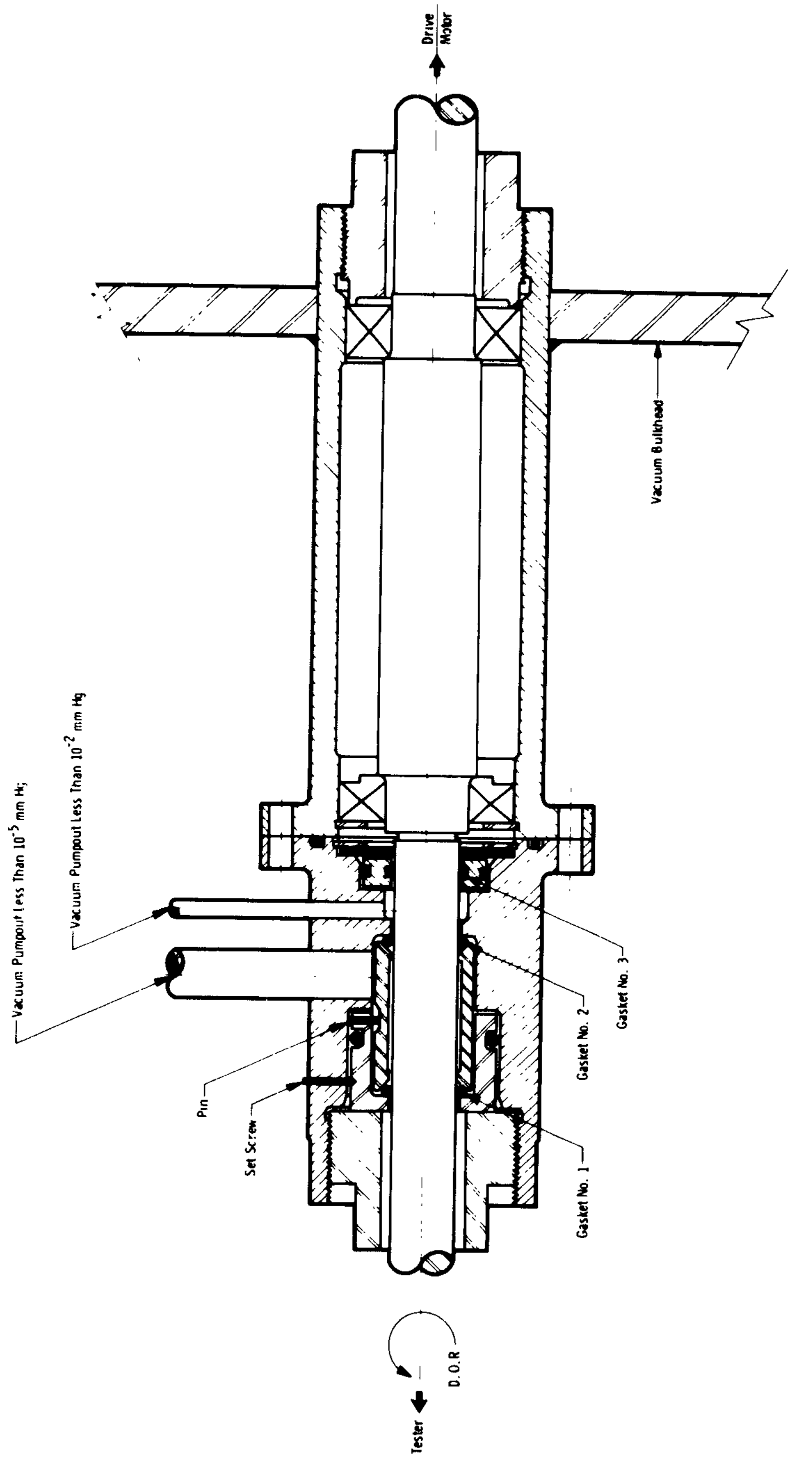


Fig. 7 Rotary Drive Vacuum Seal

Fig. 8 Test Assembly as Used in Test 6

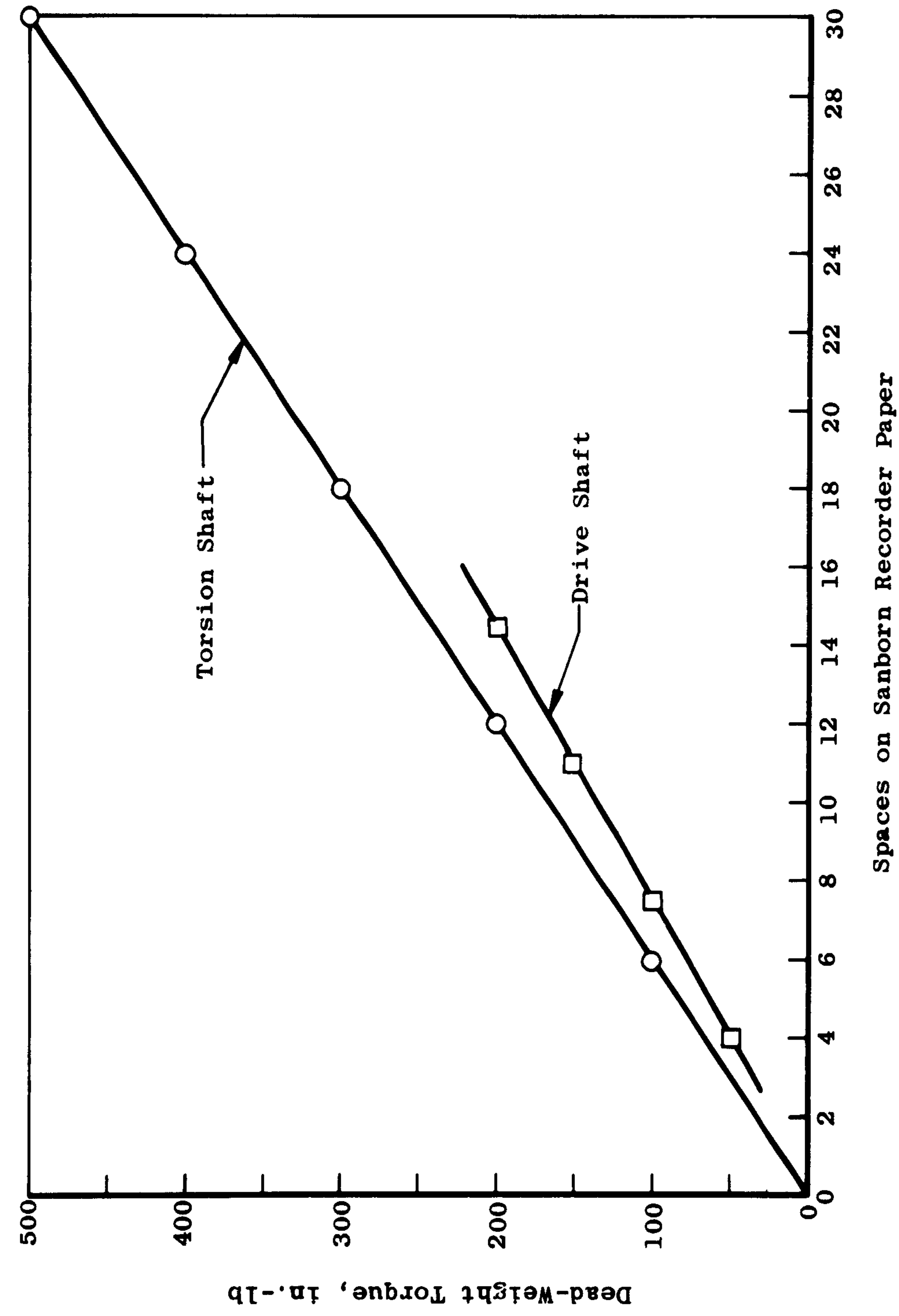
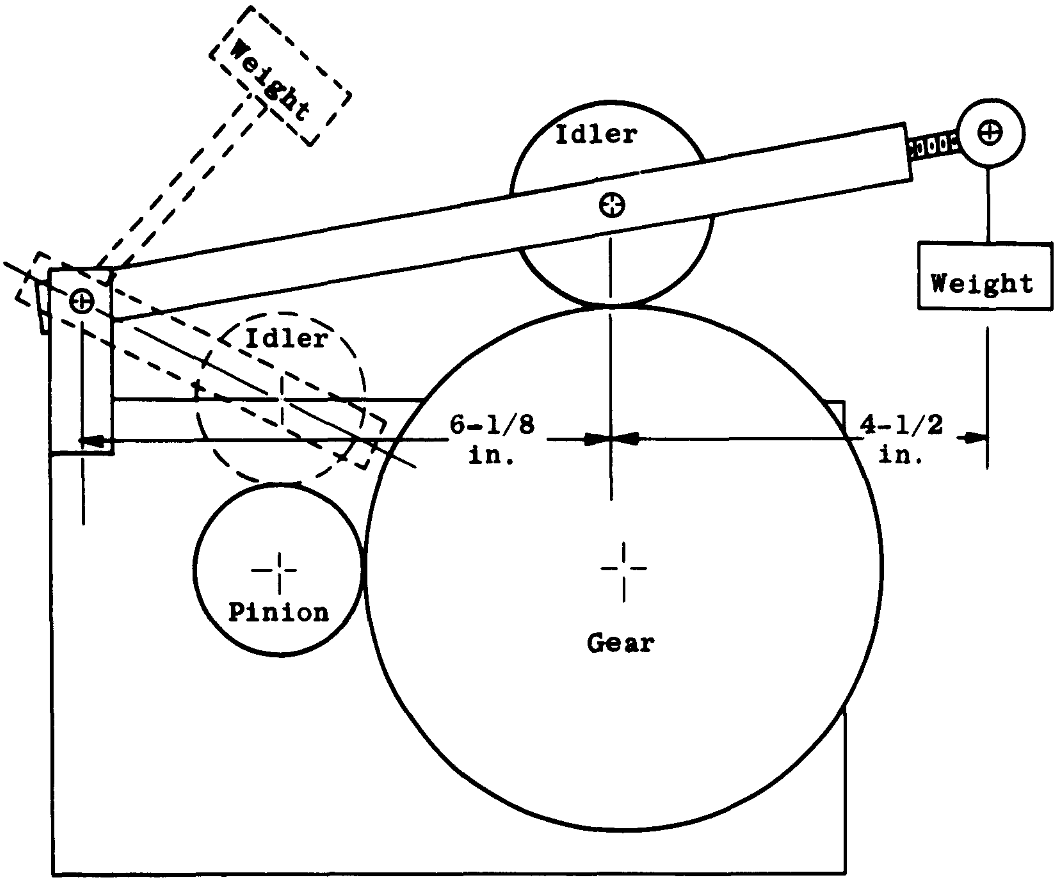


Fig. 9 Typical Calibration Data for Strain Gages from Test 5



End View of Tester, Half Scale

Test No.	Weights Added, lb			
	Left Assembly		Right Assembly	
	Pinion	Gear	Pinion	Gear
1	---	0	---	0
2	---	0.75	---	0.75
3	---	2.0	---	4.0
4	---	4.0	---	2.0
5	3.0	3.0	3.0	3.0
6	3.0	3.0	3.0	3.0
7	---	---	---	---

Fig. 10 Idler Location on Gears and Pinions with Added Weights

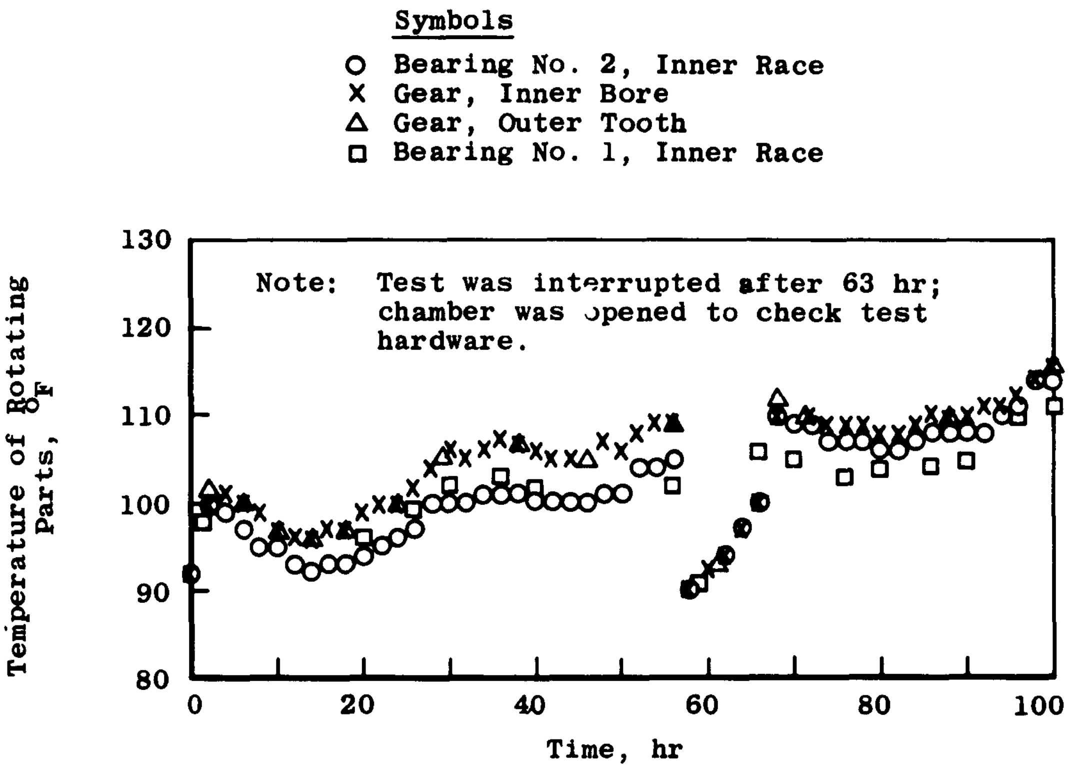


Fig. 11 Temperature of Rotating Parts versus Time

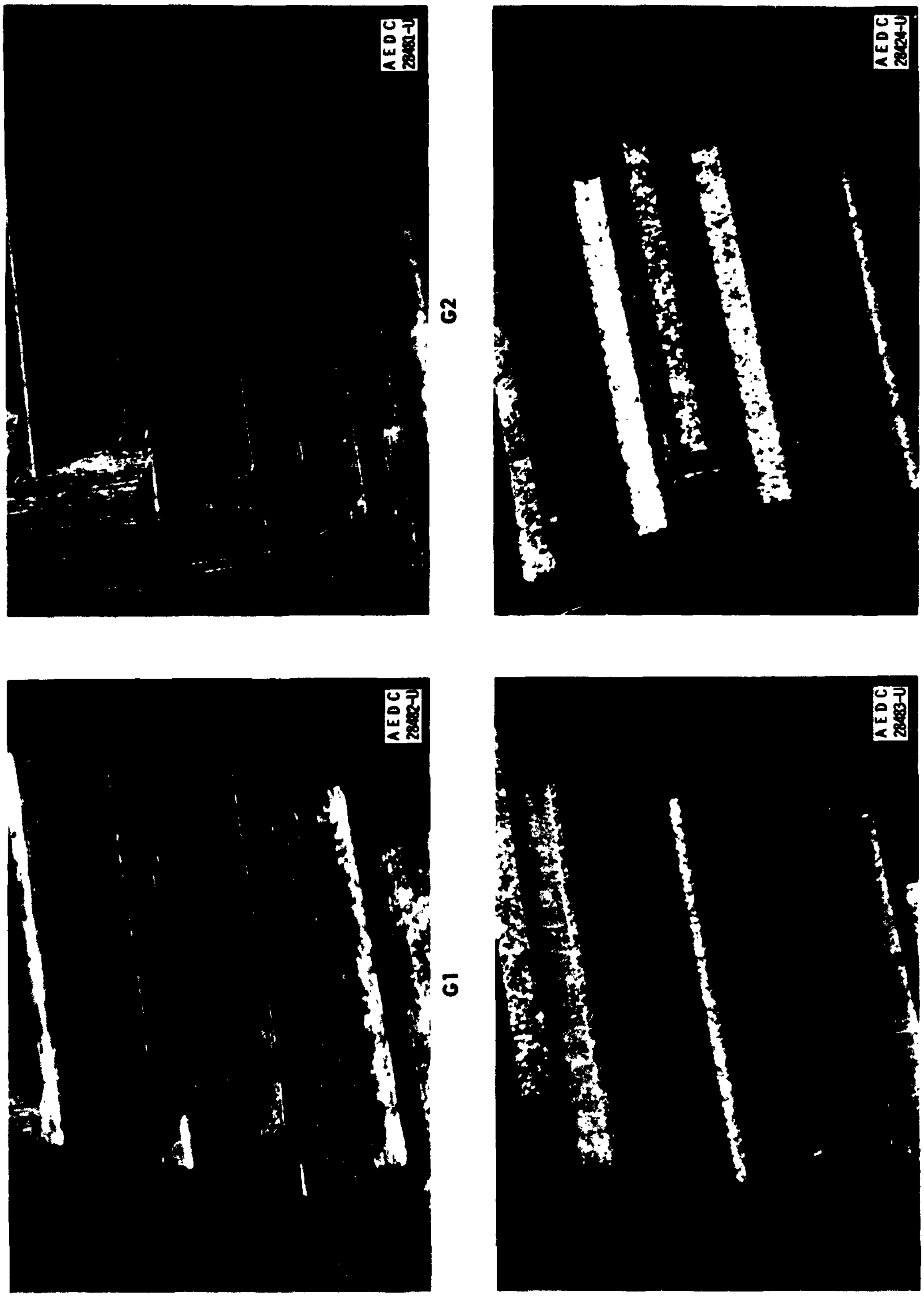


Fig 12 Test Components after Test 1

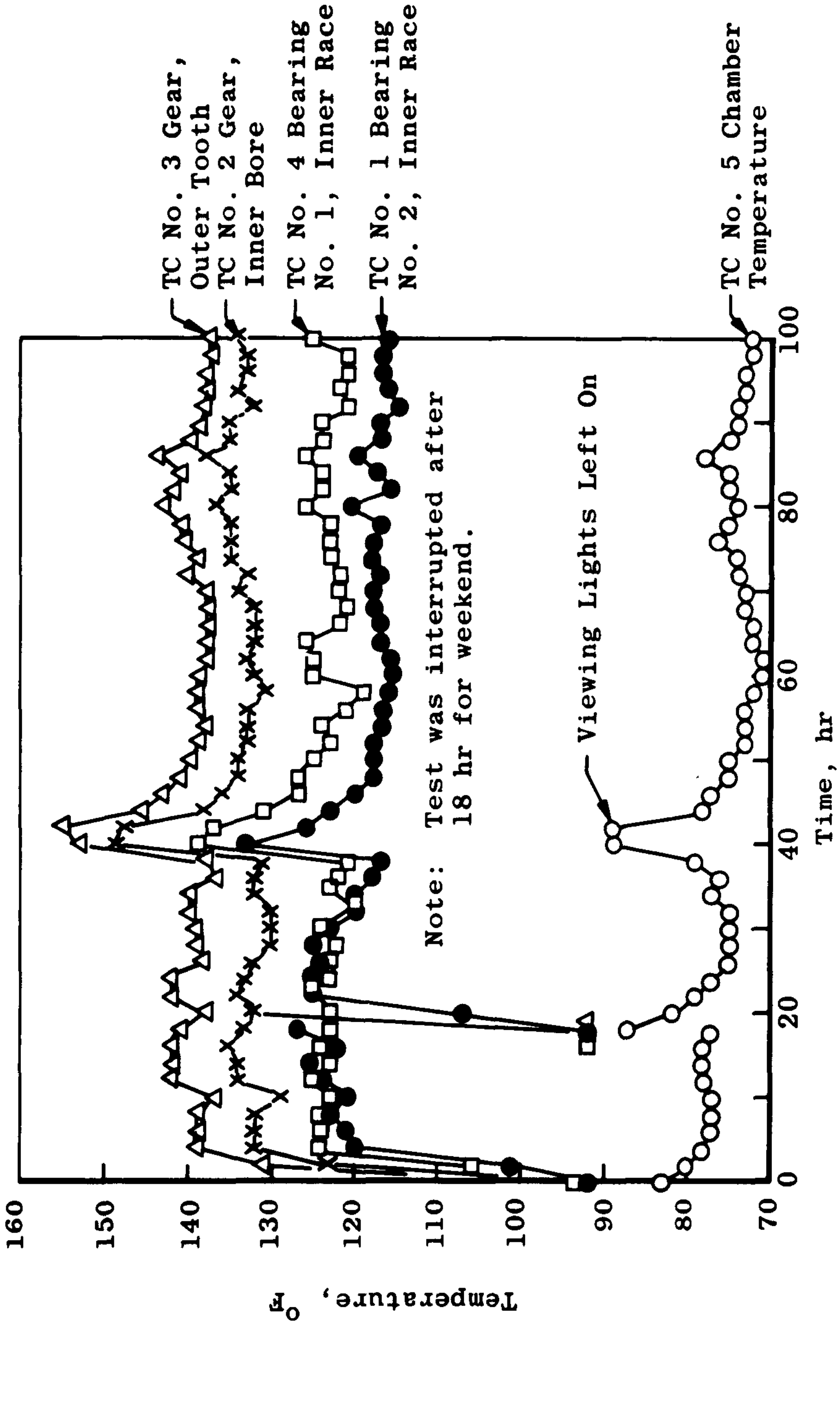


Fig. 13 Temperature Conditions for Test 2

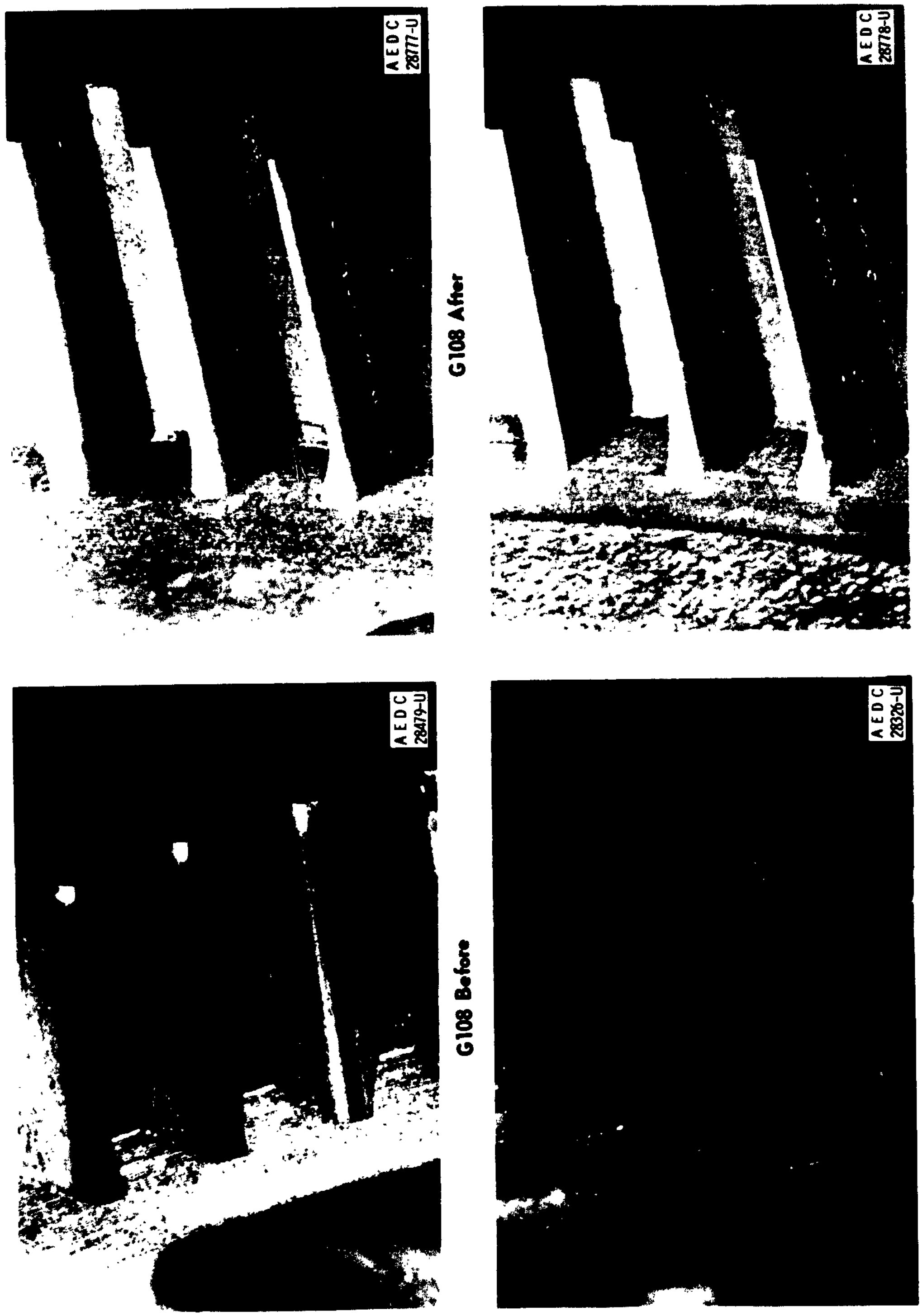
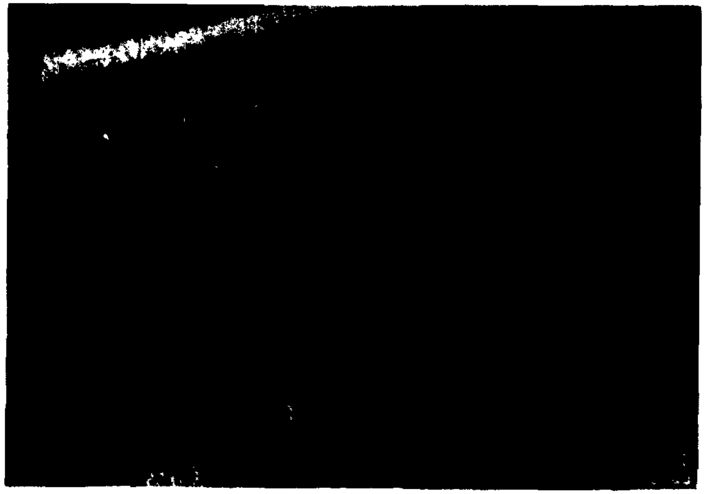


Fig. 14 Gears before and after Test 2

P108

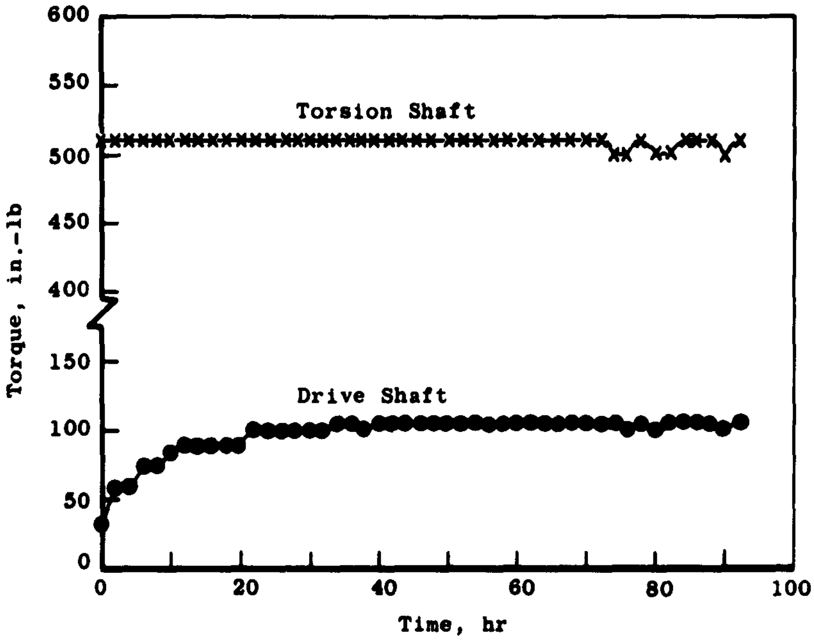


P109

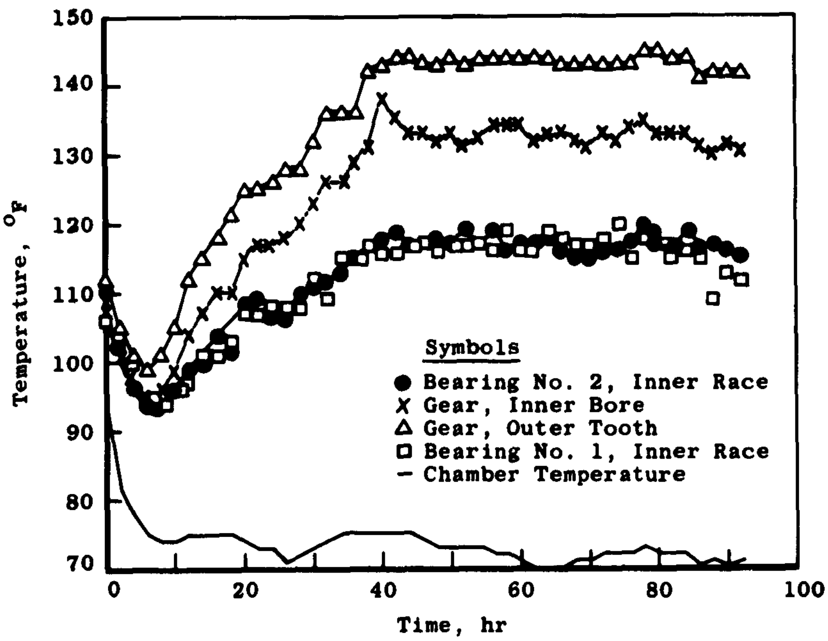
I1

I2

Fig. 15 Pinions and Idlers after Test 2

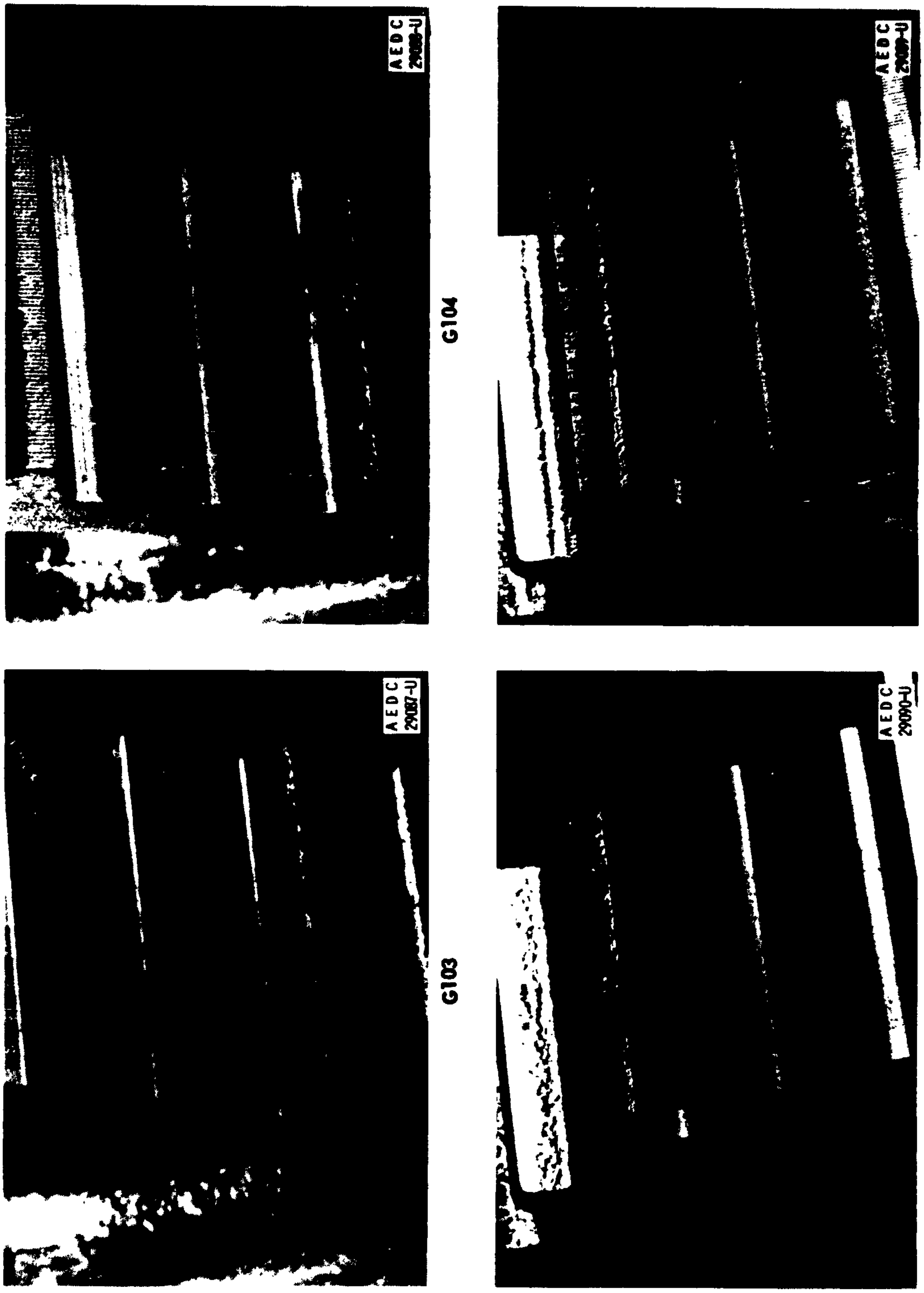


a. Torque



b. Temperature

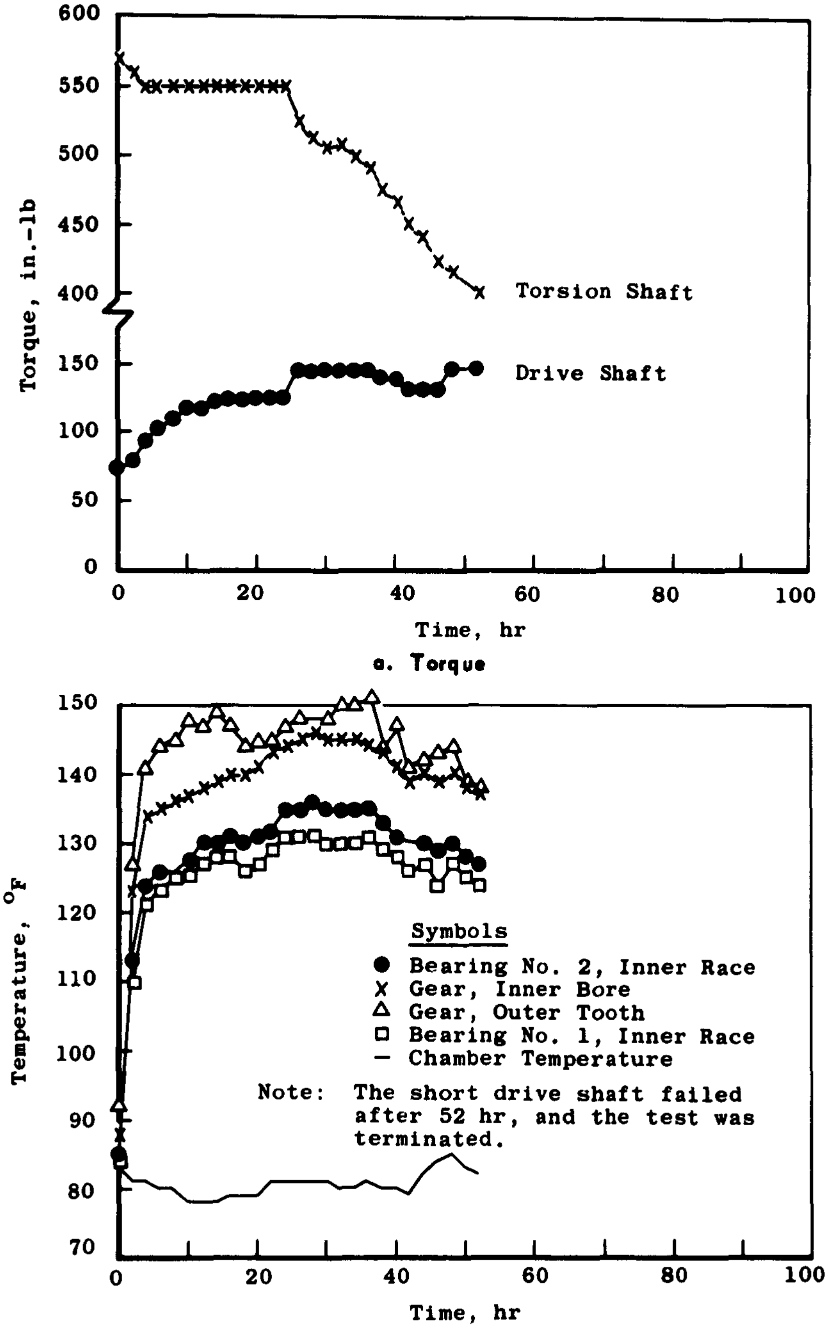
Fig. 16 Conditions for Test 3



G104 P6

G103 P104

Fig. 17 Gears and Pinions after Test 3



a. Torque

b. Temperature

Fig. 18 Conditions for Test 4

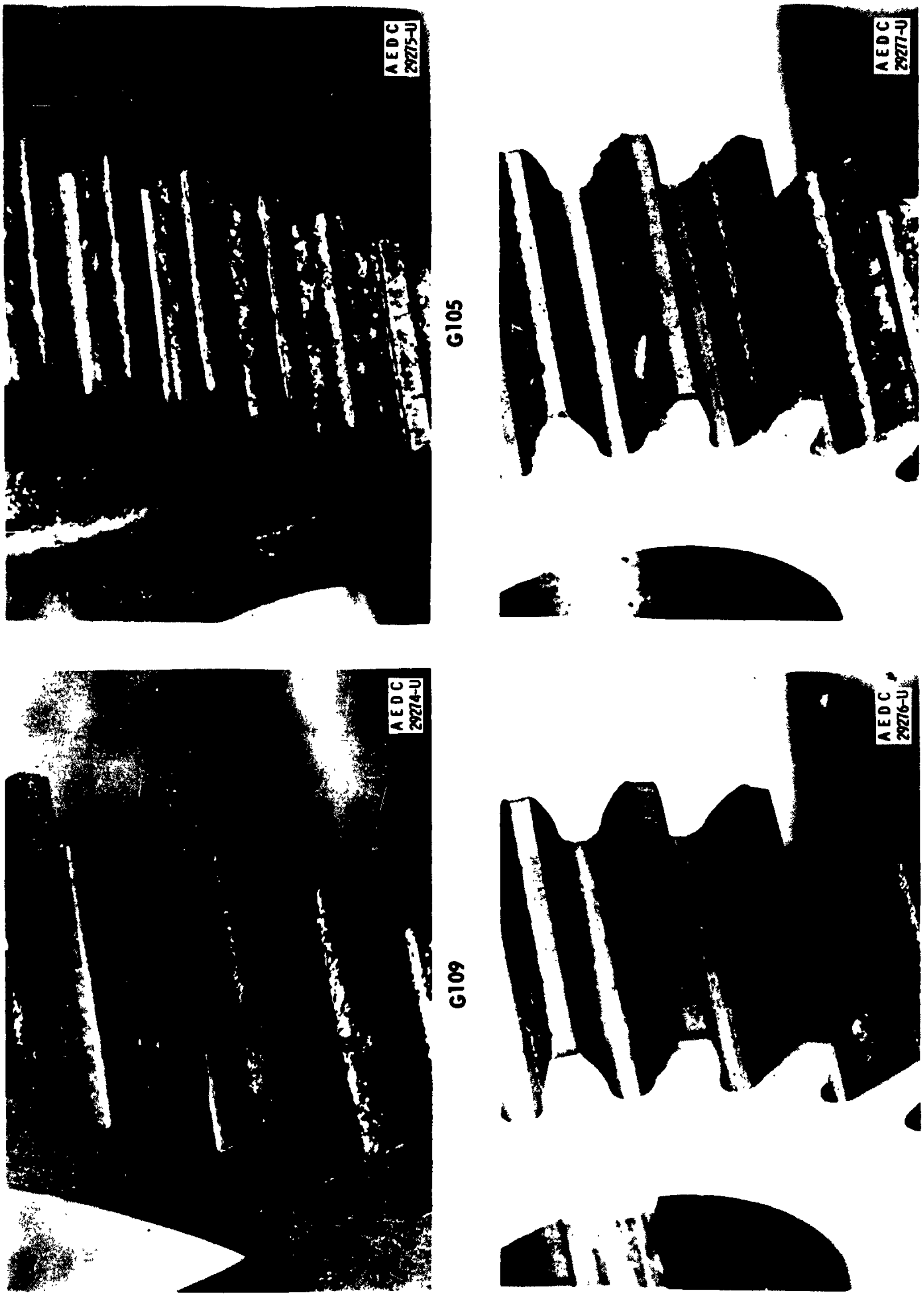
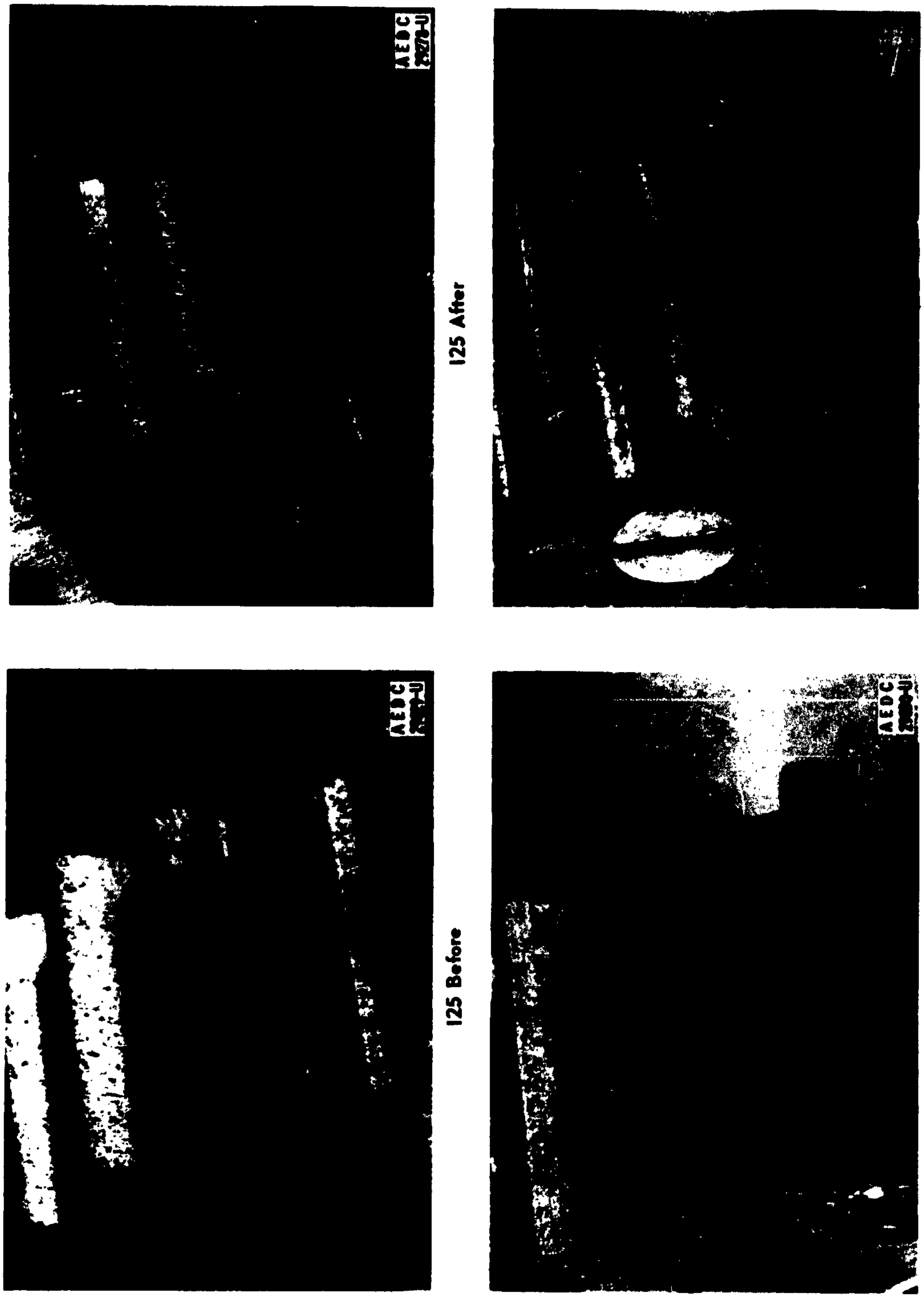


Fig. 19 Gears and Pinions after Test 4



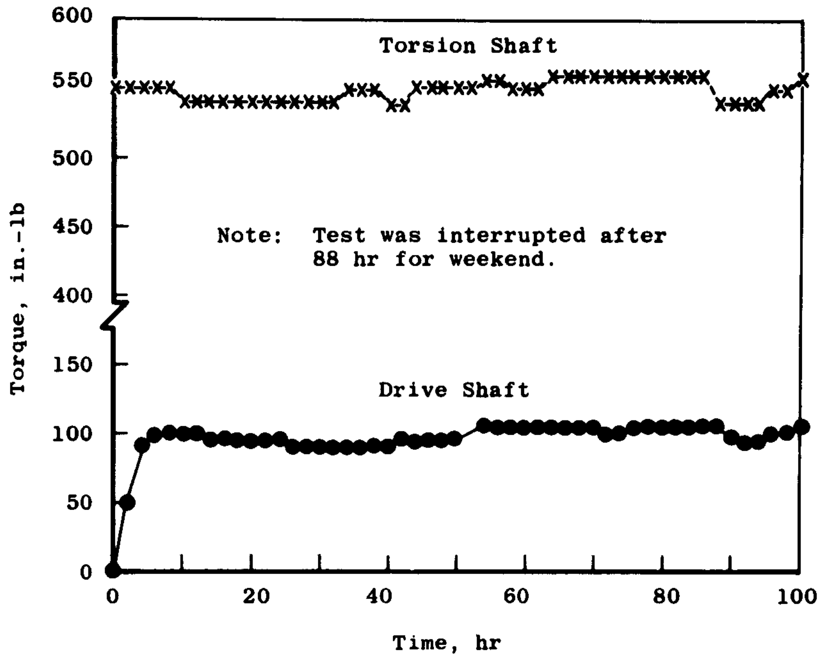
125 Before

125 After

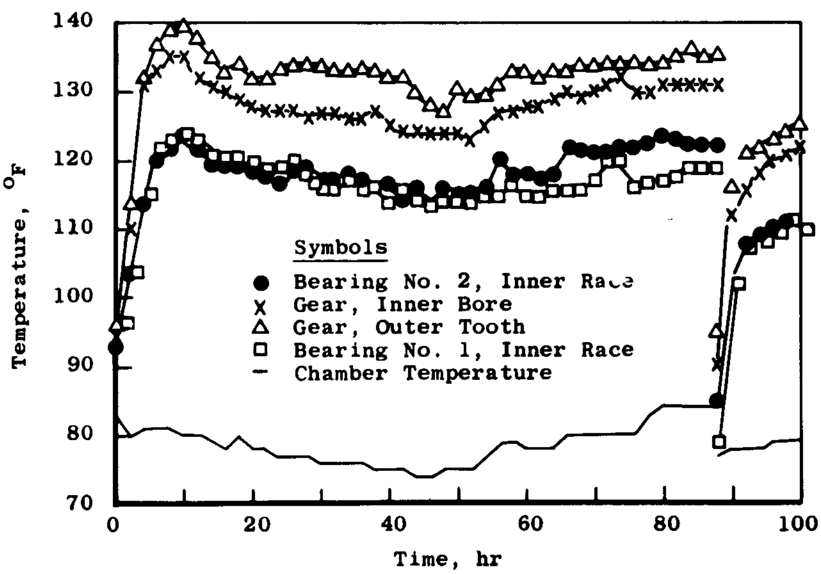
126 Before

126 After

Fig. 20 Idlers before and after Test 4

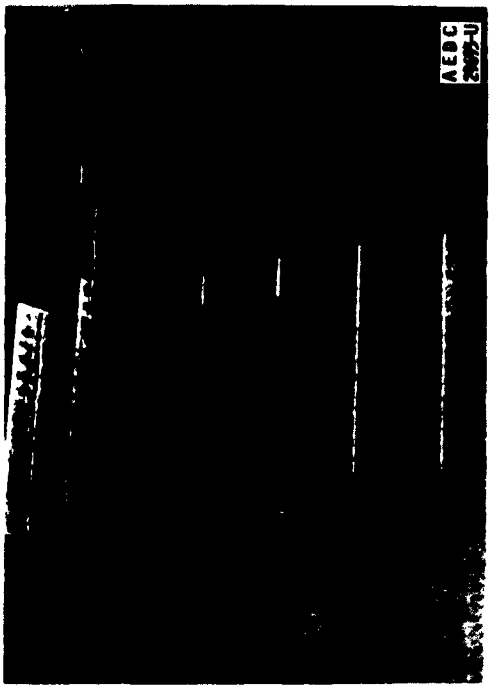


a. Torque

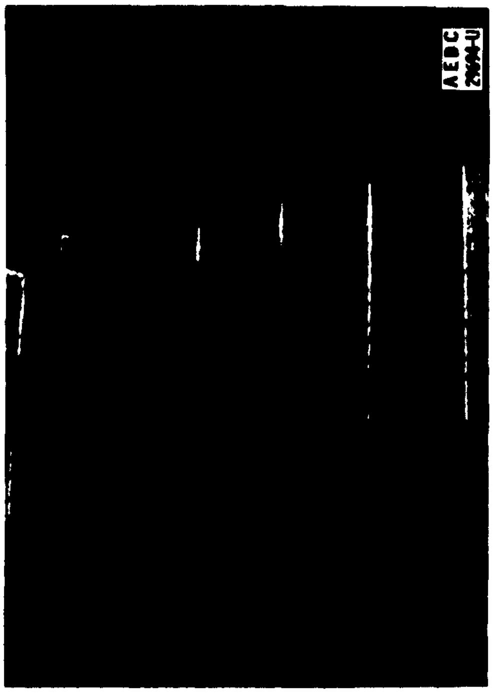


b. Temperature

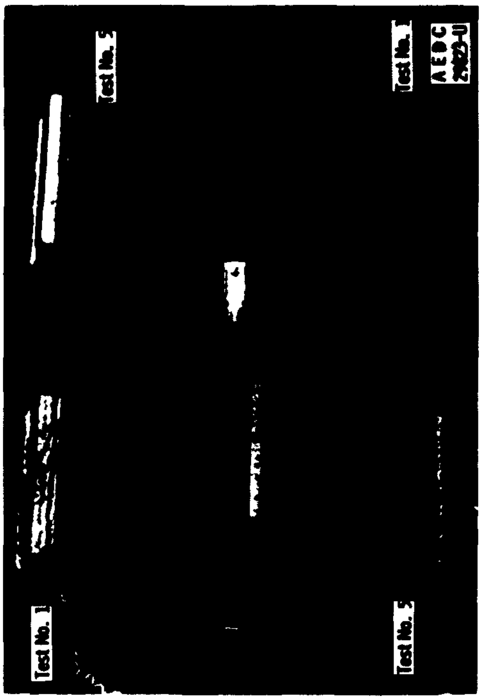
Fig. 21 Conditions for Test 5



G111

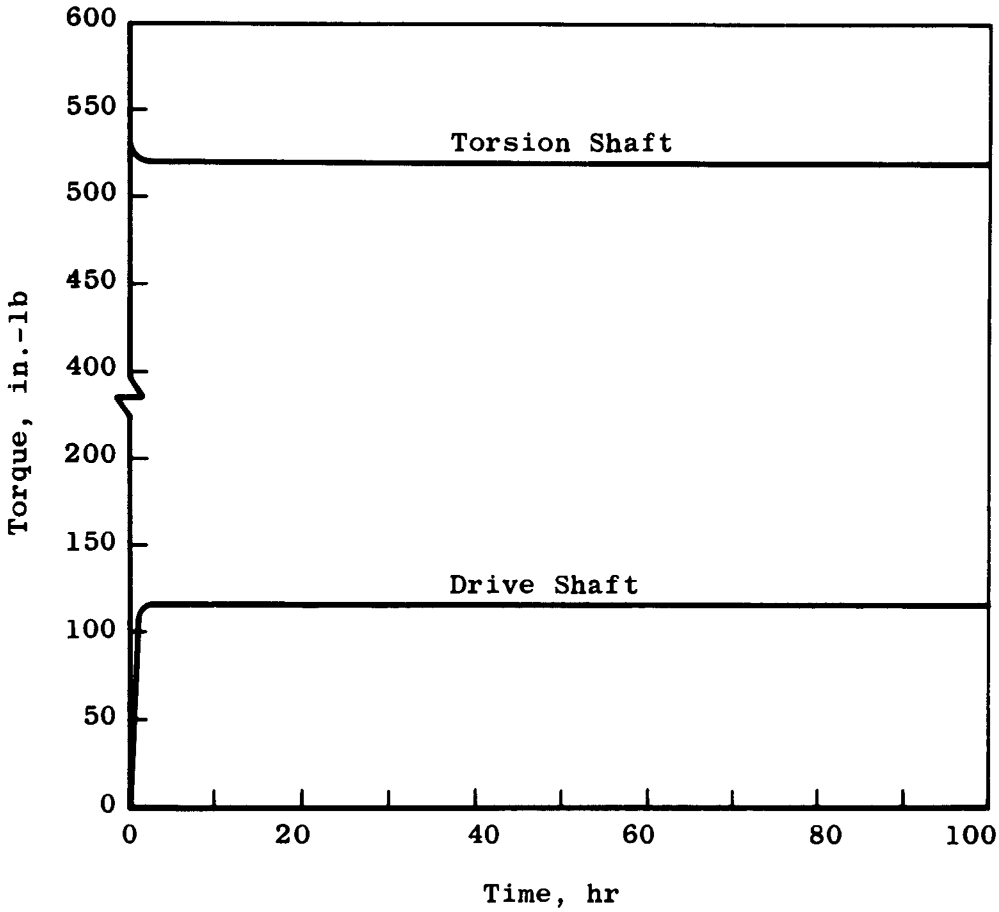


G110



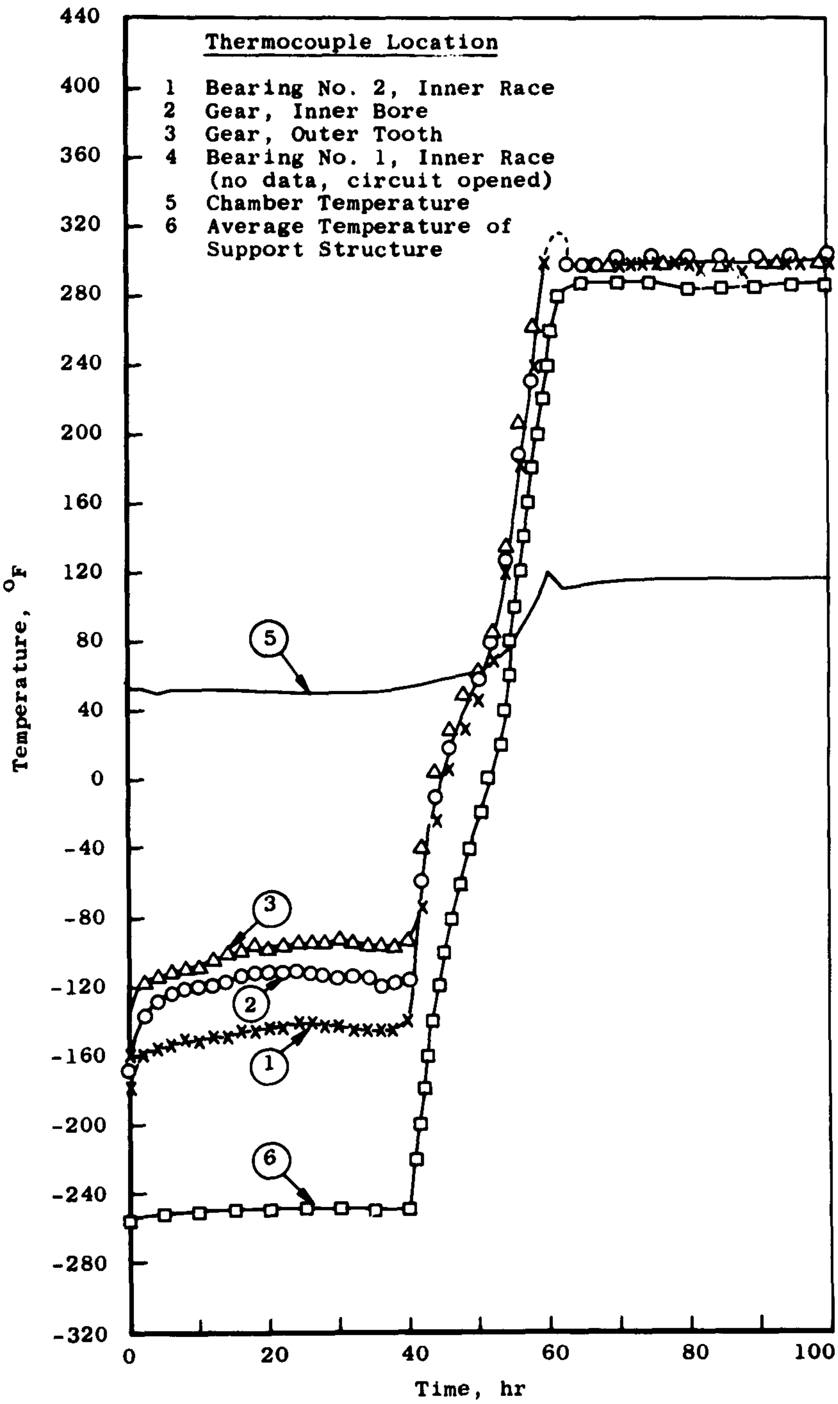
P2 P1

Fig. 22 Gears and Pinions after Test 5



a. Torque

Fig. 23 Conditions for Test 6



b. Temperature

Fig. 23 Concluded

G111

G110

P11

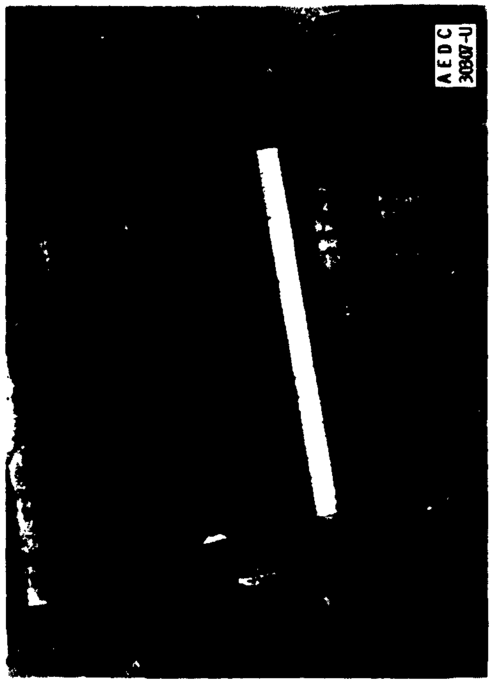
P110

Fig. 24 Gears and Pinions after Test 6

G5

G10

P8



P7

Fig. 25 Gears and Pinions after Test 7

Arnold Engineering Development Center
Arnold Air Force Station, Tennessee
Rpt. No. AEDC-TDR-63-67. OPERATIONAL EVALUATION OF DRY-LUBRICANT COMPOSITES IN A HIGH VACUUM CHAMBER. May 1963, 48 p. incl 3 refs., illus., tables.

Unclassified Report

This report contains the results of a test program to determine the operational characteristics of dry self-lubricating materials in the extremely low pressure environment of a space simulator. The test was designed to evaluate the lubrication of gears, pinions, and bearings. Four selected self-lubricating composites fabricated as bearing retainers and idler gears were tested in the 7-Ft Aerospace Research Chamber at AEDC. Three of the composites consisted of a metal matrix, polytetrafluoroethylene (PTFE), and tungsten diselenide (WSe_2), the other consisted only of PTFE and WSe_2. The three composites with the metal matrix performed satisfactorily; the fourth material did not provide an adequate lubricating film on the gears which resulted in metal-to-metal contact and high wear.

1. Low-temperature lubricants
2. Lubricants
3. Tests
4. Space environmental conditions
5. Test facilities

I. AFSC Program Area 850E, Project 7778, Task 777801
II. Contract AF 40(600)-1000
III. ARO, Inc., Arnold AF Sta, Tenn.
IV. A. G. Williams and T. L. Ridings
V. Available from OTS
VI. In ASTIA Collection

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